

# Intel® Pentium® D Processor, Intel® Pentium® Processor Extreme Edition, Intel® Pentium® 4 Processor and Intel® Core™2 Duo Extreme Processor

## Thermal and Mechanical Design Guidelines (TMDG)

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— *For the Intel® Pentium® D Processor 800<sup>Δ</sup> and 900<sup>Δ</sup>  
Sequences, Intel® Pentium® Processor Extreme Edition  
840<sup>Δ</sup>, 955<sup>Δ</sup>, 965<sup>Δ</sup>, and Intel® Pentium® 4 Processor 6x1<sup>Δ</sup>  
Sequence and Intel® Core™2 Duo Extreme Processor  
X6800<sup>Δ</sup>*

*January 2007*



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# Contents

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1	Introduction .....	9
1.1	Document Goals and Scope .....	9
1.1.1	Importance of Thermal Management .....	9
1.1.2	Document Goals .....	9
1.1.3	Document Scope .....	10
1.2	References .....	11
1.3	Definition of Terms .....	12
2	Processor Thermal/Mechanical Information .....	15
2.1	Mechanical Requirements .....	15
2.1.1	Processor Package .....	15
2.1.2	Heatsink Attach .....	17
2.1.2.1	General Guidelines .....	17
2.1.2.2	Heatsink Clip Load Requirement .....	17
2.1.2.3	Additional Guidelines .....	18
2.2	Thermal Requirements .....	18
2.2.1	Processor Case Temperature .....	19
2.2.2	Thermal Profile .....	19
2.2.3	T <sub>CONTROL</sub> .....	21
2.3	Heatsink Design Considerations .....	21
2.3.1	Heatsink Size .....	22
2.3.2	Heatsink Mass .....	23
2.3.3	Package IHS Flatness .....	23
2.3.4	Thermal Interface Material .....	24
2.4	System Thermal Solution Considerations .....	24
2.4.1	Chassis Thermal Design Capabilities .....	24
2.4.2	Improving Chassis Thermal Performance .....	24
2.4.3	Summary .....	25
2.5	System Integration Considerations .....	26
3	Thermal Metrology .....	27
3.1	Characterizing Cooling Performance Requirements .....	27
3.1.1	Example .....	28
3.2	Processor Thermal Solution Performance Assessment .....	29
3.3	Local Ambient Temperature Measurement Guidelines .....	29
3.4	Processor Case Temperature Measurement Guidelines .....	32
4	Thermal Management Logic and Thermal Monitor Feature .....	33
4.1	Processor Power Dissipation .....	33
4.2	Thermal Monitor Implementation .....	33
4.2.1	PROCHOT# Signal .....	34
4.2.2	FORCEPR# Signal .....	34
4.2.3	Thermal Control Circuit .....	35
4.2.4	Thermal Monitor 2 .....	36
4.2.5	Operation and Configuration .....	37
4.2.6	On-Demand Mode .....	38



	4.2.7	System Considerations .....	38
	4.2.8	Operating System and Application Software Considerations .....	39
	4.2.9	On-Die Thermal Diode.....	39
	4.2.9.1	Reading the On-Die Thermal Diode Interface .....	40
	4.2.9.2	Correction Factors for the On-Die Thermal Diode.....	40
	4.2.9.3	Thermal Diode Correction Factor .....	41
	4.2.10	THERMTRIP# Signal.....	42
	4.2.11	Cooling System Failure Warning .....	42
5		Intel® Thermal/Mechanical Reference Design Information .....	43
	5.1	ATX Heatsink Performance Targets .....	43
	5.2	Results for the ATX Reference Design .....	44
	5.2.1	Reference Heatsink Performance .....	45
	5.2.2	Acoustics .....	45
	5.2.3	Altitude.....	46
	5.2.4	Reference Heatsink Thermal Validation .....	46
	5.2.5	Fan Performance for Active Heatsink Thermal Solution.....	47
	5.3	Environmental Reliability Testing .....	48
	5.3.1	Structural Reliability Testing .....	48
	5.3.1.1	Random Vibration Test Procedure.....	48
	5.3.1.2	Shock Test Procedure .....	48
	5.3.2	Power Cycling .....	50
	5.3.3	Recommended BIOS/Processor/Memory Test Procedures .....	50
	5.4	Material and Recycling Requirements .....	50
	5.5	Safety Requirements .....	51
	5.6	Geometric Envelope for Intel Reference ATX Thermal Mechanical Design .....	51
	5.7	Reference Attach Mechanism.....	52
	5.7.1	Structural Design Strategy.....	52
	5.7.2	Mechanical Interface to the Reference Attach Mechanism .....	53
6		Acoustic Fan Speed Control .....	55
	6.1	Acoustic Fan Speed Control.....	55
	6.2	Thermal Solution Design .....	55
	6.2.1	Compliance to Thermal Profile.....	55
	6.2.2	Determine Thermistor Set Points .....	56
	6.2.3	Minimum Fan Speed Set Point.....	56
	6.3	Board and System Implementation .....	57
	6.3.1	Choosing Fan Speed Control Settings .....	57
	6.3.1.1	Temperature to begin fan acceleration .....	58
	6.3.1.2	Minimum PWM Duty Cycle.....	60
	6.4	Combining Thermistor and Thermal Diode Control.....	61
	6.5	Interaction of Thermal Profile and T <sub>CONTROL</sub> .....	61
Appendix A		LGA775 Socket Heatsink Loading .....	63
	A.1	LGA775 Socket Heatsink Considerations .....	63
	A.2	Metric for Heatsink Preload for ATX/uATX Designs Non-Compliant with Intel® Reference Design .....	63
	A.2.1	Heatsink Preload Requirement Limitations.....	63
	A.2.2	Motherboard Deflection Metric Definition.....	64
	A.2.3	Board Deflection Limits .....	65
	A.2.4	Board Deflection Metric Implementation Example.....	66
	A.2.5	Additional Considerations .....	67
	A.2.5.1	Motherboard Stiffening Considerations.....	68



A.3	Heatsink Selection Guidelines.....	68
Appendix B	Heatsink Clip Load Metrology.....	69
B.1	Overview .....	69
B.2	Test Preparation.....	69
B.2.1	Heatsink Preparation.....	69
B.2.2	Typical Test Equipment .....	72
B.3	Test Procedure Examples.....	73
B.3.1	Time-Zero, Room Temperature Preload Measurement.....	73
B.3.2	Preload Degradation under Bake Conditions .....	73
Appendix C	Thermal Interface Management.....	75
C.1	Bond Line Management .....	75
C.2	Interface Material Area.....	75
C.3	Interface Material Performance.....	75
Appendix D	Case Temperature Reference Metrology.....	77
D.1	Objective and Scope .....	77
D.2	Supporting Test Equipment.....	78
D.3	Thermal Calibration and Controls.....	79
D.4	IHS Groove .....	79
D.5	Thermocouple Attach Procedure .....	83
D.5.1	Thermocouple Conditioning and Preparation .....	83
D.5.2	Thermocouple Attachment to the IHS.....	84
D.5.3	Solder Process .....	89
D.5.4	Cleaning and Completion of Thermocouple Installation.....	93
D.6	Thermocouple Wire Management.....	96
Appendix E	Board Level PWM and Fan Speed Control Requirements.....	97
Appendix F	Balanced Technology Extended (BTX) System Thermal Considerations.....	101
Appendix G	Mechanical Drawings .....	103
Appendix H	Intel® Enabled Reference Solution Information .....	121

## Figures

Figure 1. Package IHS Load Areas .....	15
Figure 2. Processor Case Temperature Measurement Location .....	19
Figure 3. Example Thermal Profile .....	20
Figure 4. Processor Thermal Characterization Parameter Relationships.....	28
Figure 5. Locations for Measuring Local Ambient Temperature, Active Heatsink.....	31
Figure 6. Locations for Measuring Local Ambient Temperature, Passive Heatsink .....	31
Figure 7. Concept for Clocks under Thermal Monitor Control.....	35
Figure 8. Thermal Monitor 2 Frequency and Voltage Ordering .....	37
Figure 9. Intel® RCFH-4 Reference Design (Exploded View .....	44
Figure 10. Random Vibration PSD.....	48
Figure 11. Shock Acceleration Curve.....	49
Figure 12. Upward Board Deflection during Shock.....	52
Figure 13. Reference Clip/Heatsink Assembly .....	53



Figure 14. Critical Parameters for Interfacing to Reference Clip .....	54
Figure 15. Critical Core Dimension.....	54
Figure 16. Thermistor Set Points .....	56
Figure 17. Example Acoustic Fan Speed Control Implementation .....	57
Figure 18. Fan Speed Control.....	58
Figure 19. Temperature Range = 5 °C .....	59
Figure 20. Temperature Range = 10 °C.....	60
Figure 21. Diode and Thermistor .....	61
Figure 22. Board Deflection Definition .....	65
Figure 23. Example: Defining Heatsink Preload Meeting Board Deflection Limit .....	67
Figure 24. Load Cell Installation in Machined Heatsink Base Pocket (Bottom View) ...	70
Figure 25. Load Cell Installation in Machined Heatsink Base Pocket (Side View).....	71
Figure 26. Preload Test Configuration.....	71
Figure 27. Omega Thermocouple.....	79
Figure 28. 775-LAND LGA Package Reference Groove Drawing.....	80
Figure 29. 775-LAND LGA Package Reference Groove Drawing Alternate Orientation ..	81
Figure 30. IHS Groove on the 775-LAND LGA Package.....	82
Figure 31. IHS Groove Orientation Relative to the LGA775 Socket.....	82
Figure 32. Inspection of Insulation on Thermocouple.....	83
Figure 33. Bending the Tip of the Thermocouple .....	84
Figure 34. Securing Thermocouple Wires with Kapton* Tape Prior to Attach .....	84
Figure 35. Thermocouple Bead Placement.....	85
Figure 36. Position Bead on the Groove Step.....	86
Figure 37. Detailed Thermocouple Bead Placement .....	86
Figure 38. Third Tape Installation .....	87
Figure 39. Measuring Resistance between Thermocouple and IHS .....	87
Figure 40. Applying Flux to the Thermocouple Bead .....	88
Figure 41. Cutting Solder .....	88
Figure 42. Positioning Solder on IHS .....	89
Figure 43. Solder Station Setup .....	90
Figure 44. View Through Lens at Solder Station.....	91
Figure 45. Moving Solder back onto Thermocouple Bead .....	91
Figure 46. Removing Excess Solder .....	92
Figure 47. Thermocouple placed into groove .....	93
Figure 48. Removing Excess Solder .....	93
Figure 49. Filling Groove with Adhesive .....	94
Figure 50. Application of Accelerant.....	94
Figure 51. Removing Excess Adhesive from IHS .....	95
Figure 52. Finished Thermocouple Installation .....	95
Figure 53. Thermocouple Wire Management.....	96
Figure 54. FSC Definition Example.....	98
Figure 55. System Airflow Illustration with System Monitor Point Area Identified ....	102
Figure 56. Thermal Sensor Location Illustration .....	102
Figure 57. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 1).....	104
Figure 58. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 2).....	105
Figure 59. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 3).....	106
Figure 60. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 1) .....	107
Figure 61. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 2) .....	108
Figure 62. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 3) .....	109



Figure 63. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 4) .....	110
Figure 64. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 5) .....	111
Figure 65. ATX Reference Clip (Sheet 1) .....	112
Figure 66. ATX Reference Clip (Sheet 2) .....	113
Figure 67. Reference Fastener (Sheet 1) .....	114
Figure 68. Reference Fastener (Sheet 2) .....	115
Figure 69. Reference Fastener (Sheet 3) .....	116
Figure 70. Reference Fastener (Sheet 4) .....	117
Figure 71. Intel® RCFH-4 Reference Solution Assembly .....	118
Figure 72. Intel® RCFH-4 Reference Solution Assembly (Sheet 2) .....	119

## Tables

Table 1. Heatsink Inlet Temperature .....	24
Table 2. Thermal Diode Interface .....	40
Table 3. ATX Heatsink Performance Targets .....	43
Table 4. ATX Reference Heatsink (RCFH-4) Performance for 775_VR_CONFIG_05B Processors .....	45
Table 5. Acoustic Results .....	45
Table 6. Fan Electrical Performance Requirements .....	47
Table 7. Board Deflection Configuration Definitions .....	64
Table 8. Typical Test Equipment .....	72
Table 9. FSC Definitions .....	97
Table 10. ATX FSC Settings .....	99
Table 11. Balanced Technology Extended (BTX) FSC Settings .....	100
Table 12. Intel® Representative Contact for Licensing Information .....	121
Table 13. Intel® Reference Component ATX Thermal Solution Providers .....	121
Table 14. Intel® Reference Component for Balanced Technology Extended (BTX) Thermal Solution Providers .....	122



## Revision History

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Revision Number	Description	Date
-001	<ul style="list-style-type: none"><li>Initial Release</li></ul>	April 2005
-002	<ul style="list-style-type: none"><li>Added information for Intel® Pentium® D processor</li><li>Updated drawings for reference fastener</li><li>Clarified Fan Speed Control information</li></ul>	May 2005
-003	<ul style="list-style-type: none"><li>Added information for the Intel Pentium processor Extreme Edition 955.</li></ul>	December 2005
-004	<ul style="list-style-type: none"><li>Added information for the Intel Pentium D processor 900 sequence</li></ul>	January 2006
-005	<ul style="list-style-type: none"><li>Added information for the Intel Pentium 4 processor 6x1 sequence</li></ul>	January 2006
-006	<ul style="list-style-type: none"><li>Added information for the Intel Pentium processor Extreme Edition 965.</li></ul>	March 2006
-007	<ul style="list-style-type: none"><li>Added information for the Intel Pentium D processor 960.</li></ul>	April 2006
-008	<ul style="list-style-type: none"><li>Added information for the Intel Pentium D processor 915 and 945</li><li>Added Figure 29, "775-LAND LGA Package Reference Groove Drawing Alternate Orientation"</li></ul>	July 2006
-009	<ul style="list-style-type: none"><li>Added support for the Intel® Core™2 Duo Extreme Processor X6800</li></ul>	July 2006
-010	<ul style="list-style-type: none"><li>Added support for the Intel Pentium D processor 925</li></ul>	September 2006
-011	<ul style="list-style-type: none"><li>Added support for the Intel Pentium D processor 935</li><li>Updated Table 6.</li></ul>	January 2007





# 1 Introduction

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## 1.1 Document Goals and Scope

### 1.1.1 Importance of Thermal Management

The objective of thermal management is to ensure that the temperatures of all components in a system are maintained within their functional temperature range. Within this temperature range, a component is expected to meet its specified performance. Operation outside the functional temperature range can degrade system performance, cause logic errors, or cause component and/or system damage. Temperatures exceeding the maximum operating limit of a component may result in irreversible changes in the operating characteristics of this component.

In a system environment, the processor temperature is a function of both system and component thermal characteristics. The system level thermal constraints consist of the local ambient air temperature and airflow over the processor as well as the physical constraints at and above the processor. The processor temperature depends in particular on the component power dissipation, the processor package thermal characteristics, and the processor thermal solution.

All of these parameters are affected by the continued push of technology to increase processor performance levels and packaging density (more transistors). As operating frequencies increase and packaging size decreases, the power density increases while the thermal solution space and airflow typically become more constrained or remains the same within the system. The result is an increased importance on system design to ensure that thermal design requirements are met for each component, including the processor, in the system.

### 1.1.2 Document Goals

Depending on the type of system and the chassis characteristics, new system and component designs may be required to provide adequate cooling for the processor. The goal of this document is to provide an understanding of these thermal characteristics and discuss guidelines for meeting the thermal requirements imposed on single processor systems using the Intel® Core™2 Duo Extreme processor X6800, Intel® Pentium® D processor 800 and 900 sequences, the Intel® Pentium® processor Extreme Edition 840, 955, 965, and Intel® Pentium® 4 processor 6x1 sequence.

The concepts given in this document are applicable to any system form factor. Specific examples used will be the Intel enabled reference solution for ATX/uATX systems. See the applicable Balanced Technology Extended (BTX) form factor reference documents to design a thermal solution for that form factor.



### 1.1.3 Document Scope

This design guide supports the following processors:

- Intel® Pentium® Processor Extreme Edition 840
- Intel® Pentium® D processor 840, 830 and 820
- Intel® Pentium® processor Extreme Edition 955 and 965
- Intel® Pentium® D processor 960, 950, 945, 940, 935, 930, 925, 920, and 915
- Intel® Pentium® 4 processor 661, 651, 641, and 631
- Intel® Core™2 Duo Extreme Processor X6800

In this document when a reference is made to “the processor” it is intended that this includes all the processors supported by this document. If needed for clarity, the specific processor will be listed.

**Note:** In this document Pentium D processor 800 sequence refers to processor numbers 840, 830, and 820.

**Note:** In this document Pentium D processor 900 sequence refers to processor numbers 960, 950, 945, 940, 935, 930, 925, 920, and 915.

**Note:** In this document Pentium 4 processor 6x1 sequence refers to processor numbers 661, 651, 641, and 631.

In this document, when a reference is made to “the datasheet”, the reader should refer to the *Intel® Pentium® Processor Extreme Edition 840<sup>Δ</sup> Datasheet*, *Intel® Pentium® D Processor 840<sup>Δ</sup>, 830<sup>Δ</sup>, and 820<sup>Δ</sup> Datasheet*, *Intel® Pentium® D Processor 900 Sequence and Intel® Pentium® Processor Extreme Edition 955<sup>Δ</sup> and 965<sup>Δ</sup> Datasheet*, *Intel® Pentium® 4 Processor 6x1<sup>Δ</sup> Sequence Datasheet*, or *Intel® Core™2 Duo Extreme Processor X6800<sup>Δ</sup> and Intel® Core™2 Duo Processor E6000<sup>Δ</sup> and E4000<sup>Δ</sup> Sequence Datasheet* as appropriate.

Chapter 2 discusses package thermal mechanical requirements to design a thermal solution for these processors in the context of personal computer applications. Chapter 3 discusses the thermal solution considerations and metrology recommendations to validate a processor thermal solution. Chapter 4 addresses the benefits of the processor’s integrated thermal management logic for thermal design.

Chapter 5 gives information on the Intel reference thermal solution for the processor. Chapter 6 discusses the implementation of acoustic fan speed control.

THE PHYSICAL DIMENSIONS AND THERMAL SPECIFICATIONS OF THE PROCESSOR THAT ARE USED IN THIS DOCUMENT ARE FOR ILLUSTRATION ONLY. REFER TO THE DATASHEET FOR THE PRODUCT DIMENSIONS, THERMAL POWER DISSIPATION AND MAXIMUM CASE TEMPERATURE. IN CASE OF CONFLICT, THE DATA IN THE DATASHEET SUPERSEDES ANY DATA IN THIS DOCUMENT.



## 1.2 References

Material and concepts available in the following documents may be beneficial when reading this document.

Document	Document Link
<i>Intel® Pentium® Processor Extreme Edition 840<sup>Å</sup> Datasheet</i>	<a href="http://developer.intel.com/design/pentiumXE/datashts/306831.htm">http://developer.intel.com/design/pentiumXE/datashts/306831.htm</a>
<i>Intel® Pentium® D Processor 840, 830<sup>Å</sup> and 820<sup>Å</sup> Datasheet</i>	<a href="http://developer.intel.com/design/PentiumD/datashts/307506.htm">http://developer.intel.com/design/PentiumD/datashts/307506.htm</a>
<i>Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal and Mechanical Design Guidelines</i>	<a href="http://developer.intel.com/design/Pentium4/guides/302553.htm">http://developer.intel.com/design/Pentium4/guides/302553.htm</a>
<i>Intel® Pentium® D Processor 900 Sequence and Intel® Pentium® Processor Extreme Edition 955<sup>Å</sup>, 965<sup>Å</sup> Datasheet</i>	<a href="http://developer.intel.com/design/pentiumXE/datashts/310306.htm">http://developer.intel.com/design/pentiumXE/datashts/310306.htm</a>
<i>Intel® Pentium® 4 Processor 6x1<sup>Å</sup> Sequence Datasheet</i>	<a href="http://developer.intel.com/design/pentium4/datashts/310308.htm">http://developer.intel.com/design/pentium4/datashts/310308.htm</a>
<i>Intel® Core™2 Duo Extreme Processor X6800<sup>Å</sup> and Intel® Core™2 Duo Processor E6000<sup>Å</sup> and E4000<sup>Å</sup> Sequence Datasheet</i>	<a href="http://www.intel.com/design/processor/datashts/313278.htm">www.intel.com/design/processor/datashts/313278.htm</a>
<i>LGA775 Socket Mechanical Design Guide</i>	<a href="http://developer.intel.com/design/Pentium4/guides/302666.htm">http://developer.intel.com/design/Pentium4/guides/302666.htm</a>
<i>Boxed Intel® Pentium® 4 Processor in the 775-Land LGA Package - Integration Video</i>	<a href="http://www.intel.com/go/integration">http://www.intel.com/go/integration</a>
<i>Fan Specification for 4-wire PWM Controlled Fans</i>	<a href="http://www.formfactors.org/">http://www.formfactors.org/</a>
<i>Performance ATX Desktop System Thermal Design Suggestions</i>	<a href="http://www.formfactors.org/">http://www.formfactors.org/</a>
<i>Performance microATX Desktop System Thermal Design Suggestions</i>	<a href="http://www.formfactors.org/">http://www.formfactors.org/</a>
<i>Balanced Technology Extended (BTX) System Design Guide</i>	<a href="http://www.formfactors.org/">http://www.formfactors.org/</a>

## 1.3 Definition of Terms

Term	Description
$T_A$	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heatsink or at the fan inlet for an active heatsink.
$T_C$	The case temperature of the processor, measured at the geometric center of the topside of the IHS.
$T_E$	The ambient air temperature external to a system chassis. This temperature is usually measured at the chassis air inlets.
$T_S$	Heatsink temperature measured on the underside of the heatsink base, at a location corresponding to $T_C$ .
$T_{C-MAX}$	The maximum case temperature as specified in a component specification.
$\Psi_{CA}$	Case-to-ambient thermal characterization parameter (psi). A measure of thermal solution performance using total package power. Defined as $(T_C - T_A) / \text{Total Package Power}$ . Note: Heat source must be specified for $\Psi$ measurements.
$\Psi_{CS}$	Case-to-sink thermal characterization parameter. A measure of thermal interface material performance using total package power. Defined as $(T_C - T_S) / \text{Total Package Power}$ . Note: Heat source must be specified for $\Psi$ measurements.
$\Psi_{SA}$	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as $(T_S - T_A) / \text{Total Package Power}$ . Note: Heat source must be specified for $\Psi$ measurements.
TIM	Thermal Interface Material (TIM) is the thermally conductive compound between the heatsink and the processor case. This material fills the air gaps and voids, and enhances the transfer of the heat from the processor case to the heatsink.
$P_{MAX}$	The maximum power dissipated by a semiconductor component.
TDP	Thermal Design Power (TDP) is a power dissipation target based on worst-case applications. Thermal solutions should be designed to dissipate the thermal design power.
IHS	Integrated Heat Spreader (IHS) is a thermally conductive lid integrated into a processor package to improve heat transfer to a thermal solution through heat spreading.
LGA775 Socket	The surface mount socket designed to accept the processors in the 775-Land LGA package.
ACPI	Advanced Configuration and Power Interface.
Bypass	Bypass is the area between a passive heatsink and any object that can act to form a duct. For this example, it can be expressed as a dimension away from the outside dimension of the fins to the nearest surface.
Thermal Monitor	A feature on the processor that attempts to keep the processor die temperature within factory specifications.
TCC	Thermal Control Circuit. Thermal Monitor uses the TCC to reduce die temperature by lowering effective processor frequency when the die temperature has exceeded its operating limits.



Term	Description
$T_{\text{DIODE}}$	Temperature reported from the on-die thermal diode.
FSC	Fan Speed Control. FSC is the thermal solution that includes a variable fan speed which is driven by a PWM signal and uses the on-die thermal diode as a reference to change the duty cycle of the PWM signal.
$T_{\text{CONTROL\_BASE}}$	Constant from the processor datasheet that is added to the $T_{\text{CONTROL\_OFFSET}}$ that results in the value for $T_{\text{CONTROL}}$
$T_{\text{CONTROL\_OFFSET}}$	Value read by the BIOS from a processor MSR and added to the $T_{\text{CONTROL\_BASE}}$ that results in the value for $T_{\text{CONTROL}}$
$T_{\text{CONTROL}}$	$T_{\text{CONTROL}}$ is the specification limit for use with the on-die thermal diode.
PWM	Pulse width modulation is a method of controlling a variable speed fan. The enabled 4 wire fans use the PWM duty cycle % from the fan speed controller to modulate the fan speed.
Thermal Diode Correction Offset	Thermal Diode Correction Offset is a correction factor to correct for temperature shift resulting from a perceived shift in ideality for thermal sensors that use the diode model to measure the processor temperature Note: This only applies to Pentium 4 processor 6x1 sequence, Pentium processor Extreme Edition 955, 965, and Pentium D processor 900 sequence.
Thermal Diode Offset	Value read by the BIOS from a processor MSR and added to the Thermal Diode Base that results in the value for Thermal Diode Correction Offset
Thermal Diode Base	Constant from the processor datasheet that is added to the Thermal Diode Offset that result in the value for Thermal Diode Correction Offset.
Health Monitor Component	Any standalone or integrated component that is capable of reading the processor temperature and providing the PWM signal to the 4 pin fan header.
BTX	Balanced Technology Extended. Enhanced form factor specification for desktop platforms.
TMA	Thermal Module Assembly. The heatsink, fan and duct assembly for the BTX thermal solution.





## 2 Processor Thermal/Mechanical Information

### 2.1 Mechanical Requirements

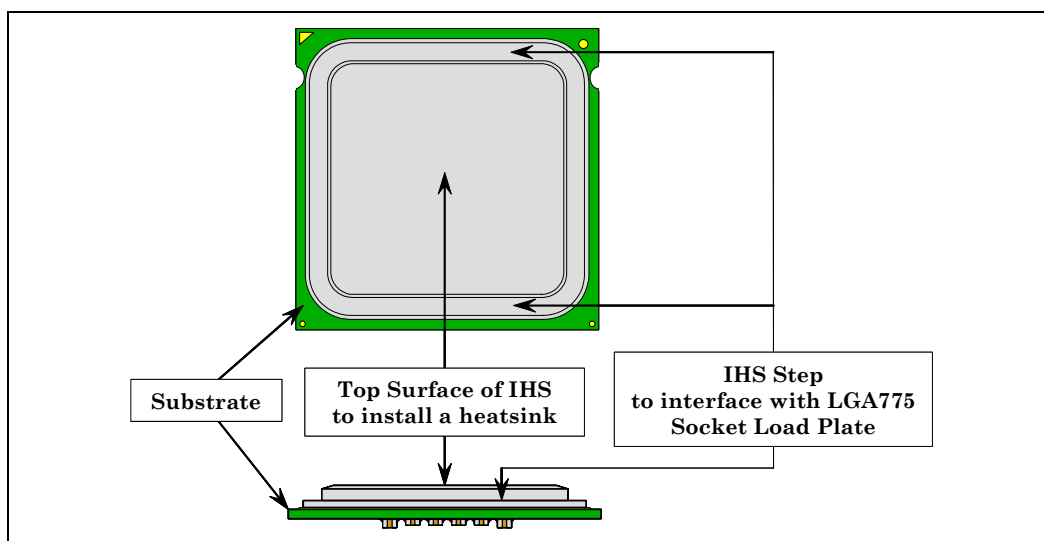
#### 2.1.1 Processor Package

The processors covered in this document are packaged in a 775-Land LGA package that interfaces with the motherboard via a LGA775 socket. Refer to the datasheet for detailed mechanical specifications.

The processor connects to the motherboard through a land grid array (LGA) surface mount socket. The socket contains 775 contacts arrayed about a cavity in the center of the socket with solder balls for surface mounting to the motherboard. The socket is named LGA775 socket. A description of the socket can be found in the *LGA775 Socket Mechanical Design Guide*.

The package includes an integrated heat spreader (IHS) that is shown in Figure 1 for illustration only. Refer to the processor datasheet for further information. In case of conflict, the package dimensions in the processor datasheet supersedes dimensions provided in this document.

Figure 1. Package IHS Load Areas



The primary function of the IHS is to transfer the non-uniform heat distribution from the die to the top of the IHS, out of which the heat flux is more uniform and spread over a larger surface area (not the entire IHS area). This allows more efficient heat



transfer out of the package to an attached cooling device. The top surface of the IHS is designed to be the interface for contacting a heatsink.

The IHS also features a step that interfaces with the LGA775 socket load plate, as described in *LGA775 Socket Mechanical Design Guide*. The load from the load plate is distributed across two sides of the package onto a step on each side of the IHS. It is then distributed by the package across all of the contacts. When correctly actuated, the top surface of the IHS is above the load plate allowing proper installation of a heatsink on the top surface of the IHS. After actuation of the socket load plate, the seating plane of the package is flush with the seating plane of the socket. Package movement during socket actuation is along the Z direction (perpendicular to substrate) only. Refer to the *LGA775 Socket Mechanical Design Guide* for further information about the LGA775 socket.

The processor package has mechanical load limits that are specified in the processor datasheet. The specified maximum static and dynamic load limits should not be exceeded during their respective stress conditions. These include heatsink installation, removal, mechanical stress testing, and standard shipping conditions.

- When a compressive static load is necessary to ensure thermal performance of the thermal interface material between the heatsink base and the IHS, it should not exceed the corresponding specification given in the processor datasheet.
- When a compressive static load is necessary to ensure mechanical performance, it should remain in the minimum/maximum range specified in the processor datasheet
- The heatsink mass can also generate additional dynamic compressive load to the package during a mechanical shock event. Amplification factors due to the impact force during shock must be taken into account in dynamic load calculations. The total combination of dynamic and static compressive load should not exceed the processor datasheet compressive dynamic load specification during a vertical shock. For example, with a 0.550 kg [1.2 lb] heatsink, an acceleration of 50G during an 11 ms trapezoidal shock with an amplification factor of 2 results in approximately a 539 N [117 lbf] dynamic load on the processor package. If a 178 N [40 lbf] static load is also applied on the heatsink for thermal performance of the thermal interface material the processor package could see up to a 717 N [156 lbf]. The calculation for the thermal solution of interest should be compared to the processor datasheet specification.

No portion of the substrate should be used as a load-bearing surface.

Finally, the processor datasheet provides package handling guidelines in terms of maximum recommended shear, tensile and torque loads for the processor IHS relative to a fixed substrate. These recommendations should be followed in particular for heatsink removal operations.





## 2.1.2 Heatsink Attach

### 2.1.2.1 General Guidelines

There are no features on the LGA775 socket to directly attach a heatsink: a mechanism must be designed to attach the heatsink directly to the motherboard. In addition to holding the heatsink in place on top of the IHS, this mechanism plays a significant role in the robustness of the system in which it is implemented, in particular:

- Ensuring thermal performance of the thermal interface material (TIM) applied between the IHS and the heatsink. A TIM based on phase change materials is very sensitive to applied pressure: the higher the pressure, the better the initial performance. A TIM such as thermal greases is not as sensitive to applied pressure. Designs should consider a possible decrease in applied pressure over time due to potential structural relaxation in retention components.
- Ensuring system electrical, thermal, and structural integrity under shock and vibration events. The mechanical requirements of the heatsink attach mechanism depend on the mass of the heatsink and the level of shock and vibration that the system must support. The overall structural design of the motherboard and the system have to be considered when designing the heatsink attach mechanism. Their design should provide a means for protecting LGA775 socket solder joints. One of the strategies for mechanical protection of the socket is to use a preload and high stiffness clip. This strategy is implemented by the reference design and described in Section 5.7.

**Note:** Package pull-out during mechanical shock and vibration is constrained by the LGA775 socket load plate (refer to the *LGA775 Socket Mechanical Design Guide* for further information).

### 2.1.2.2 Heatsink Clip Load Requirement

The attach mechanism for the heatsink developed to support the processor should create a static preload on the package between **18 lbf** and **70 lbf** throughout the life of the product for designs compliant with the Intel reference design assumptions:

- 72 mm x 72 mm mounting hole span (refer to Figure 57)
- And no board stiffening device (backing plate, chassis attach, etc.).

The minimum load is required to protect against fatigue failure of socket solder joint in temperature cycling.

It is important to take into account potential load degradation from creep over time when designing the clip and fastener to the required minimum load. This means that, depending on clip stiffness, the initial preload at beginning of life of the product may be significantly higher than the minimum preload that must be met throughout the life of the product. For additional guidelines on mechanical design, in particular on designs departing from the reference design assumptions refer to Appendix A.

For clip load metrology guidelines, refer to Appendix B.



### 2.1.2.3 Additional Guidelines

In addition to the general guidelines given above, the heatsink attach mechanism for the processor should be designed to the following guidelines:

- *Holds the heatsink in place under mechanical shock and vibration events and applies force to the heatsink base to maintain desired pressure on the thermal interface material.* Note that the load applied by the heatsink attach mechanism must comply with the package specifications described in the processor datasheet. One of the key design parameters is the height of the top surface of the processor IHS above the motherboard. The IHS height from the top of board is expected to vary from 7.517 mm to 8.167 mm. This data is provided for information only, and should be derived from:
  - The height of the socket seating plane above the motherboard after reflow, given in the *LGA775 Socket Mechanical Design Guide* with its tolerances
  - The height of the package, from the package seating plane to the top of the IHS, and accounting for its nominal variation and tolerances that are given in the corresponding processor datasheet.
- *Engages easily, and if possible, without the use of special tools.* In general, the heatsink is assumed to be installed after the motherboard has been installed into the chassis.
- *Minimizes contact with the motherboard surface during installation and actuation to avoid scratching the motherboard.*

## 2.2 Thermal Requirements

Refer to the datasheet for the processor thermal specifications. The majority of processor power is dissipated through the IHS. There are no additional components (e.g., BSRAMs) that generate heat on this package. The amount of power that can be dissipated as heat through the processor package substrate and into the socket is usually minimal.

The thermal limits for the processor are the Thermal Profile and  $T_{\text{CONTROL}}$ . The Thermal Profile defines the maximum case temperature as a function of power being dissipated.  $T_{\text{CONTROL}}$  is a specification used in conjunction with the temperature reported by the on-die thermal diode and a fan speed control method. Designing to these specifications allows optimization of thermal designs for processor performance and acoustic noise reduction.

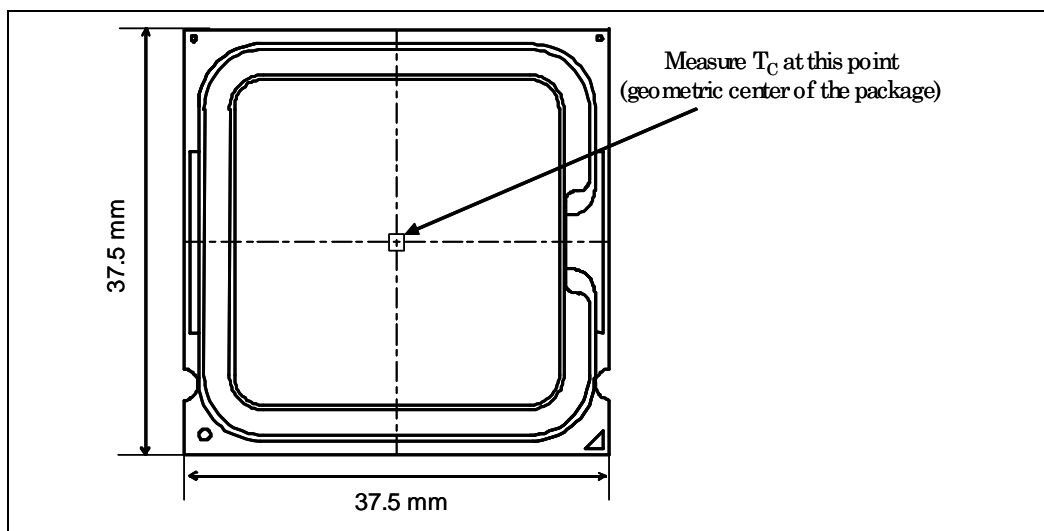


## 2.2.1 Processor Case Temperature

For the processor, the case temperature is defined as the temperature measured at the geometric center of the package on the surface of the IHS. For illustration, Figure 2 shows the measurement location for a 37.5 mm x 37.5 mm [1.474 in x 1.474 in] 775-Land LGA processor package with a 28.7 mm x 28.7 mm [1.13 in x 1.13 in] IHS top surface. Techniques for measuring the case temperature are detailed in Section 3.4.

**Note:** In case of conflict, the package dimensions in the processor datasheet supersedes dimensions provided in this document.

**Figure 2. Processor Case Temperature Measurement Location**



## 2.2.2 Thermal Profile

The Thermal Profile defines the maximum case temperature as a function of processor power dissipation. The TDP and Maximum Case Temperature are defined as the maximum values of the thermal profile. By design the thermal solutions must meet the thermal profile for all system operating conditions and processor power levels.

The slope of the thermal profile was established assuming a generational improvement in thermal solution performance of about 10% over the previous Intel reference design. This performance is expressed as the slope on the thermal profile and can be thought of as the thermal resistance of the heatsink attached to the processor,  $\Psi_{CA}$  (Refer to Section 3.1). The intercept on the thermal profile assumes a maximum ambient operating condition that is consistent with the available chassis solutions.

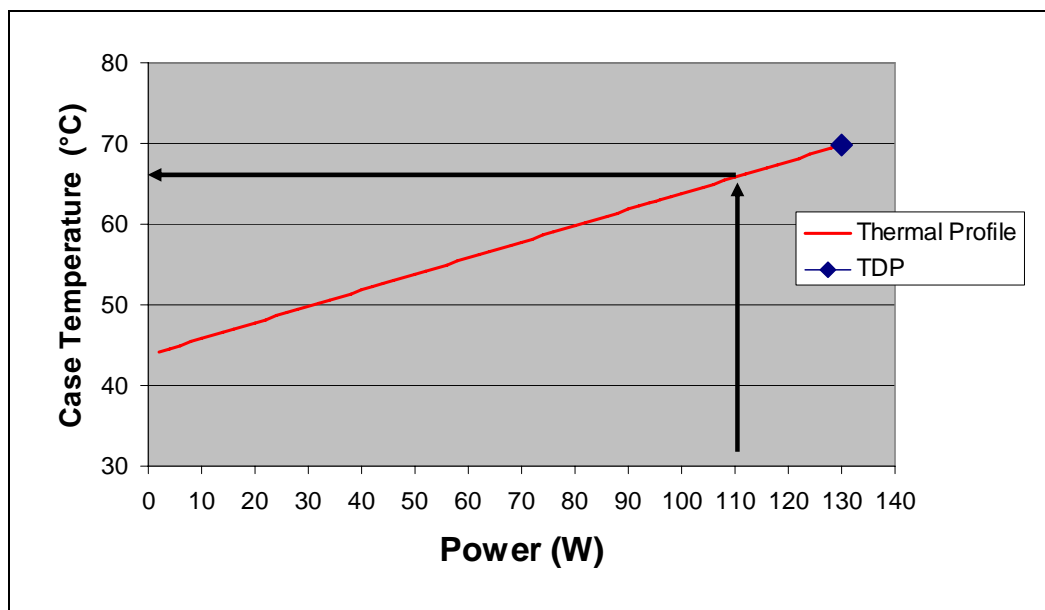
For these processors, there are two thermal profiles to consider. This document will focus on the development of thermal solutions to meet the thermal profile for 775\_VR\_CONFIG\_05B processors (TDP = 130 W). See the processor datasheet for the thermal profile and additional discussion.



The thermal profiles for the Intel Pentium processor Extreme Edition 840, 955, 965, and Intel Pentium D processor 800, 900 sequences are defined such that a single thermal solution (e.g., RCFH-4 or BTX TMA Type I reference designs) can be used for all 775\_VR\_CONFIG\_05B processors (TDP = 130 W). The thermal profile for Intel Pentium D 775\_VR\_CONFIG\_05A processors (TDP = 95 W) and the 775\_VR\_CONFIG\_05B Intel® Core™2 Duo Extreme Processor X6800 (TDP = 95 W) is also defined such that a single thermal solution (e.g., RCBFH-3 or BTX TMA Type II reference designs) would be compliant. See Chapter 5 for a discussion of the RCFH-4 and the *Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal and Mechanical Design Guidelines* for information on the RCBFH-3.

To determine compliance to the thermal profile, a measurement of the actual processor power dissipation is required. Contact your Intel sales representative for assistance in processor power measurement. The measured power is plotted on the Thermal Profile to determine the maximum case temperature. Using the example in Figure 3 for a processor dissipating ~110 W, the maximum case temperature is ~66 °C. See the datasheet for the thermal profile.

Figure 3. Example Thermal Profile





### 2.2.3 $T_{\text{CONTROL}}$

$T_{\text{CONTROL}}$  defines the maximum operating temperature for the on-die thermal diode when the thermal solution fan speed is being controlled by the on-die thermal diode. The  $T_{\text{CONTROL}}$  parameter defines a very specific processor operating region where fan speed can be reduced. This allows the system integrator a method to reduce the acoustic noise of the processor cooling solution, while maintaining compliance to the processor thermal specification.

The value of  $T_{\text{CONTROL}}$  is driven by a number of factors. One of the most significant is the processor idle power. As a result, a processor with a high  $T_{\text{CONTROL}}$  will dissipate more power than a part with lower value of  $T_{\text{CONTROL}}$  when running the same application.

The value of  $T_{\text{CONTROL}}$  is calculated such that regardless of the individual processor's  $T_{\text{CONTROL}}$  value, the thermal solution should perform similarly. The higher power of some parts is offset by a higher value of  $T_{\text{CONTROL}}$  in such a way that they should behave virtually the same acoustically.

This is achieved, in part, by using the  $\Psi_{\text{CA}}$  vs. RPM and RPM vs. Acoustics (dBA) performance curves from the Intel enabled thermal solution. A thermal solution designed to meet the thermal profile should have similar acoustic performance for any value of  $T_{\text{CONTROL}}$ .

The value for  $T_{\text{CONTROL}}$  is calculated by the system BIOS based on values read from a factory configured processor register. The result can be used to program a fan speed control component. See the datasheet for further details on reading the register and calculating  $T_{\text{CONTROL}}$ .

See Chapter 6, Acoustic Fan Speed Control, for details on implementing a design using  $T_{\text{CONTROL}}$  and the Thermal Profile.

## 2.3 Heatsink Design Considerations

To remove the heat from the processor, three basic parameters should be considered:

- **The area of the surface on which the heat transfer takes place.** Without any enhancements, this is the surface of the processor package IHS. One method used to improve thermal performance is by attaching a heatsink to the IHS. A heatsink can increase the effective heat transfer surface area by conducting heat out of the IHS and into the surrounding air through fins attached to the heatsink base.
- **The conduction path from the heat source to the heatsink fins.** Providing a direct conduction path from the heat source to the heatsink fins and selecting materials with higher thermal conductivity typically improves heatsink performance. The length, thickness, and conductivity of the conduction path from the heat source to the fins directly impact the thermal performance of the heatsink. In particular, the quality of the contact between the package IHS and the heatsink base has a higher impact on the overall thermal solution performance as processor cooling requirements become stricter. Thermal interface material (TIM) is used to fill in the gap between the IHS and the bottom surface of the heatsink, and thereby improve the overall performance of the stack-up (IHS-TIM-



Heatsink). With extremely poor heatsink interface flatness or roughness, TIM may not adequately fill the gap. The TIM thermal performance depends on its thermal conductivity as well as the pressure applied to it. Refer to Section 2.3.4 and Appendix C for further information on TIM and on bond line management between the IHS and the heatsink base.

- **The heat transfer conditions on the surface on which heat transfer takes place.** Convective heat transfer occurs between the airflow and the surface exposed to the flow. It is characterized by the local ambient temperature of the air,  $T_A$ , and the local air velocity over the surface. The higher the air velocity over the surface, and the cooler the air, the more efficient is the resulting cooling. The nature of the airflow can also enhance heat transfer via convection. Turbulent flow can provide improvement over laminar flow. In the case of a heatsink, the surface exposed to the flow includes in particular the fin faces and the heatsink base.

**Active heatsinks** typically incorporate a fan that helps manage the airflow through the heatsink.

**Passive heatsink** solutions require in-depth knowledge of the airflow in the chassis. Typically, passive heatsinks see lower air speed. These heatsinks are, therefore, typically larger (and heavier) than active heatsinks due to the increase in fin surface required to meet a required performance. As the heatsink fin density (the number of fins in a given cross-section) increases, the resistance to the airflow increases: it is more likely that the air travels around the heatsink instead of through it, unless air bypass is carefully managed. Using air-ducting techniques to manage bypass area can be an effective method for controlling airflow through the heatsink.

### 2.3.1 Heatsink Size

The size of the heatsink is dictated by height restrictions for installation in a system and by the amount of space available on the motherboard and other considerations for component height and placement in the area potentially impacted by the processor heatsink. The height of the heatsink must comply with the requirements and recommendations published for the motherboard form factor of interest. Designing a heatsink to the recommendations may preclude using it in systems adhering strictly to the form factor requirements, while still in compliance with the form factor documentation.

For the ATX/microATX form factor, it is recommended to use:

- The ATX motherboard keep-out footprint definition and height restrictions for enabling components, defined for the platforms designed with the LGA775 socket in Appendix G of this design guide.
- The motherboard primary side height constraints defined in the *ATX Specification V2.1* and the *microATX Motherboard Interface Specification V1.1* found at <http://www.formfactors.org/>.

The resulting space available above the motherboard is generally not entirely available for the heatsink. The target height of the heatsink must take into account airflow considerations (for fan performance for example) as well as other design considerations (air duct, etc.).



For BTX form factor, it is recommended to use:

- The BTX motherboard keep-out footprint definitions and height restrictions for enabling components for platforms designed with the LGA77 socket in Appendix G of this design guide.
- An overview of other BTX system considerations for thermal solutions can be obtained in the *Balanced Technology Extended (BTX) System Design Guide v1.0* found at <http://www.formfactors.org/>.

### 2.3.2 Heatsink Mass

With the need to push air cooling to better performance, heatsink solutions tend to grow larger (increase in fin surface) resulting in increased mass. The insertion of highly thermally conductive materials like copper to increase heatsink thermal conduction performance results in even heavier solutions. As mentioned in Section 2.1, the heatsink mass must take into consideration the package and socket load limits, the heatsink attach mechanical capabilities, and the mechanical shock and vibration profile targets. Beyond a certain heatsink mass, the cost of developing and implementing a heatsink attach mechanism that can ensure the system integrity under the mechanical shock and vibration profile targets may become prohibitive.

The recommended maximum heatsink mass for the ATX thermal solution is 550 g. This mass includes the fan and the heatsink only. The attach mechanism (clip, fasteners, etc.) is not included.

The mass limit for BTX heatsinks that use Intel reference design structural ingredients is 900 grams. The BTX structural reference component strategy and design is reviewed in depth in the *Balanced Technology Extended (BTX) System Design Guide, v1.0*.

**Note:** The 550 g mass limit for ATX solutions is based on the capabilities of reference design components that retain the heatsink to the board and apply the necessary preload. Any reuse of the clip and fastener in derivative designs should not exceed 550 g. ATX designs that have a mass of greater than 550 g should analyze the preload as discussed in Appendix A and retention limits of the fastener.

### 2.3.3 Package IHS Flatness

The package IHS flatness for the product is specified in the datasheet and can be used as a baseline to predict heatsink performance during the design phase.

Intel recommends testing and validating heatsink performance in full mechanical enabling configuration to capture any impact of IHS flatness change due to combined socket and heatsink loading. While socket loading alone may increase the IHS warpage, the heatsink preload redistributes the load on the package and improves the resulting IHS flatness in the enabled state.



### 2.3.4 Thermal Interface Material

Thermal interface material application between the processor IHS and the heatsink base is generally required to improve thermal conduction from the IHS to the heatsink. Many thermal interface materials can be pre-applied to the heatsink base prior to shipment from the heatsink supplier and allow direct heatsink attach, without the need for a separate thermal interface material dispense or attach process in the final assembly factory.

All thermal interface materials should be sized and positioned on the heatsink base in a way that ensures the entire processor IHS area is covered. It is important to compensate for heatsink-to-processor attach positional alignment when selecting the proper thermal interface material size.

When pre-applied material is used, it is recommended to have a protective application tape over it. This tape must be removed prior to heatsink installation.

## 2.4 System Thermal Solution Considerations

### 2.4.1 Chassis Thermal Design Capabilities

The Intel reference thermal solutions and Intel® Boxed Processor thermal solutions assume that the chassis delivers a maximum  $T_A$  of 39 °C at the inlet of the processor fan heatsink (refer to Section 5.2.1). Table 1 shows the  $T_A$  requirements for the reference solutions.

**Table 1. Heatsink Inlet Temperature**

	ATX RCBFH-3	ATX RCFH-4	BTX Type I	BTX Type II	Boxed Processor
Performance	40 °C	39 °C	35.5 °C	35.5 °C	≤ 39 °C
Mainstream / Value	40 °C	39 °C	35.5 °C	35.5 °C	≤ 38 °C

**NOTE:**

1. Boxed Processor thermal solutions for ATX assume the use of the thermally advantaged chassis.

### 2.4.2 Improving Chassis Thermal Performance

The heat generated by components within the chassis must be removed to provide an adequate operating environment for both the processor and other system components. Moving air through the chassis brings in air from the external ambient environment and transports the heat generated by the processor and other system components out of the system. The number, size, and relative position of fans and vents determine the chassis thermal performance, and the resulting ambient temperature around the processor. The size and type (passive or active) of the thermal solution and the amount of system airflow can be traded off against each other to meet specific system design constraints. Additional constraints are board





layout, spacing, component placement, acoustic requirements and structural considerations that limit the thermal solution size. For more information, refer to the *Performance ATX Desktop System Thermal Design Suggestions* or *Performance microATX Desktop System Thermal Design Suggestions* or *Balanced Technology Extended (BTX) System Design Guide v1.0* documents available on the <http://www.formfactors.org/> web site.

In addition to passive heatsinks, fan heatsinks and system fans are other solutions that exist for cooling integrated circuit devices. For example, ducted blowers, heat pipes and liquid cooling are all capable of dissipating additional heat. Due to their varying attributes, each of these solutions may be appropriate for a particular system implementation.

To develop a reliable, cost-effective thermal solution, thermal characterization and simulation should be carried out at the entire system level, accounting for the thermal requirements of each component. In addition, acoustic noise constraints may limit the size, number, placement, and types of fans that can be used in a particular design.

To ease the burden on thermal solutions, the Thermal Monitor feature and associated logic have been integrated into the silicon of the processor. By taking advantage of the Thermal Monitor feature, system designers may reduce thermal solution cost by designing to TDP instead of maximum power. Thermal Monitor attempts to protect the processor during sustained workload above TDP. Implementation options and recommendations are described in Chapter 4.

### 2.4.3 Summary

In summary, considerations in heatsink design include:

- The local ambient temperature  $T_A$  at the heatsink that is a function of chassis design.
- The thermal design power (TDP) of the processor, and the corresponding maximum  $T_C$  as calculated from the thermal profile. These parameters are usually combined in a single cooling performance parameter,  $\Psi_{CA}$  (case to air thermal characterization parameter). More information on the definition and the use of  $\Psi_{CA}$  is provided in Section 3.1.
- Heatsink interface to IHS surface characteristics, including flatness and roughness.
- The performance of the thermal interface material used between the heatsink and the IHS.
- The required heatsink clip static load, between 18 lbf to 70 lbf throughout the life of the product (Refer to Section 2.1.2.2 for further information).
- Surface area of the heatsink.
- Heatsink material and technology.
- Volume of airflow over the heatsink surface area.
- Development of airflow entering and within the heatsink area.
- Physical volumetric constraints placed by the system



## 2.5 System Integration Considerations

*Boxed Intel® Pentium® 4 Processor in the 775-Land LGA Package - Integration Video* provides Intel's best known methods for package and heatsink installation and removal for LGA775 socket based platforms and systems manufacturing. The video is available on the Web, from <http://www.intel.com/go/integration>.

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## 3 Thermal Metrology

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This section discusses guidelines for testing thermal solutions, including measuring processor temperatures. In all cases, the thermal engineer must measure power dissipation and temperature to validate a thermal solution. To define the performance of a thermal solution the “thermal characterization parameter”,  $\Psi$  (“psi”) will be used.

### 3.1 Characterizing Cooling Performance Requirements

The idea of a “thermal characterization parameter”,  $\Psi$  (“psi”), is a convenient way to characterize the performance needed for the thermal solution and to compare thermal solutions in identical situations (same heat source and local ambient conditions). The thermal characterization parameter is calculated using total package power.

**Note:** Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by a single resistance parameter like  $\Psi$ .

The case-to-local ambient thermal characterization parameter value ( $\Psi_{CA}$ ) is used as a measure of the thermal performance of the overall thermal solution that is attached to the processor package. It is defined by the following equation, and measured in units of  $^{\circ}\text{C}/\text{W}$ :

$$\Psi_{CA} = (T_C - T_A) / P_D \text{ (Equation 1)}$$

Where:

- $\Psi_{CA}$  = Case-to-local ambient thermal characterization parameter ( $^{\circ}\text{C}/\text{W}$ )
- $T_C$  = Processor case temperature ( $^{\circ}\text{C}$ )
- $T_A$  = Local ambient temperature in chassis at processor ( $^{\circ}\text{C}$ )
- $P_D$  = Processor total power dissipation (W) (assumes all power dissipates through the IHS)

The case-to-local ambient thermal characterization parameter of the processor,  $\Psi_{CA}$ , is comprised of  $\Psi_{CS}$ , the thermal interface material thermal characterization parameter, and of  $\Psi_{SA}$ , the sink-to-local ambient thermal characterization parameter:

$$\Psi_{CA} = \Psi_{CS} + \Psi_{SA} \text{ (Equation 2)}$$

Where:

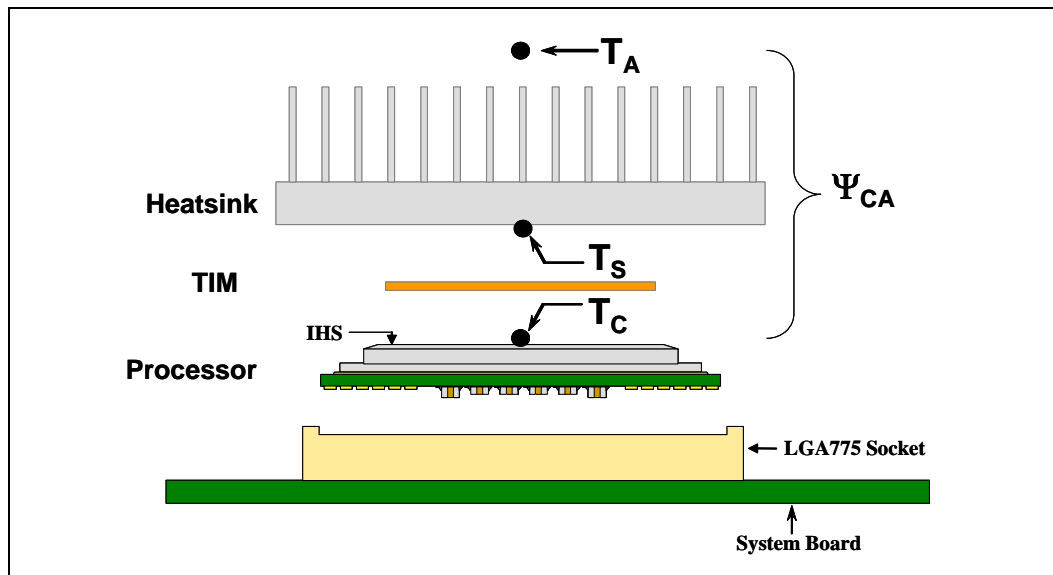
- $\Psi_{CS}$  = Thermal characterization parameter of the thermal interface material ( $^{\circ}\text{C}/\text{W}$ )
- $\Psi_{SA}$  = Thermal characterization parameter from heatsink-to-local ambient ( $^{\circ}\text{C}/\text{W}$ )

$\Psi_{CS}$  is strongly dependent on the thermal conductivity and thickness of the TIM between the heatsink and IHS.

$\Psi_{SA}$  is a measure of the thermal characterization parameter from the bottom of the heatsink to the local ambient air.  $\Psi_{SA}$  is dependent on the heatsink material, thermal conductivity, and geometry. It is also strongly dependent on the air velocity through the fins of the heatsink.

Figure 4 illustrates the combination of the different thermal characterization parameters.

**Figure 4. Processor Thermal Characterization Parameter Relationships**



### 3.1.1 Example

The cooling performance,  $\Psi_{CA}$ , is then defined using the principle of thermal characterization parameter described above:

- The case temperature  $T_{C-MAX}$  and thermal design power TDP given in the processor datasheet.
- Define a target local ambient temperature at the processor,  $T_A$ .

Since the processor thermal profile applies to all processor frequencies, it is important to identify the worst case (lowest  $\Psi_{CA}$ ) for a targeted chassis characterized by  $T_A$  to establish a design strategy.

The following provides an illustration of how one might determine the appropriate performance targets. The example power and temperature numbers used here are not related to any specific Intel processor thermal specifications, and are for illustrative purposes only.

Assume the TDP, as listed in the datasheet, is 100 W and the maximum case temperature from the thermal profile for 100 W is 67 °C. Assume, as well, that the system airflow has been designed such that the local ambient temperature is 38 °C.



Then, the following could be calculated using equation 1 provided earlier in this section:

$$\Psi_{CA} = (T_C - T_A) / TDP = (67 - 38) / 100 = 0.29 \text{ }^{\circ}\text{C/W}$$

To determine the required heatsink performance, a heatsink solution provider would need to determine  $\Psi_{CS}$  performance for the selected TIM and mechanical load configuration. If the heatsink solution were designed to work with a TIM material performing at  $\Psi_{CS} \leq 0.10 \text{ }^{\circ}\text{C/W}$ , solving for Equation 2 provided earlier in this section, the performance of the heatsink would be:

$$\Psi_{SA} = \Psi_{CA} - \Psi_{CS} = 0.29 - 0.10 = 0.19 \text{ }^{\circ}\text{C/W}$$

### 3.2 Processor Thermal Solution Performance Assessment

Thermal performance of a heatsink should be assessed using a thermal test vehicle (TTV) provided by Intel. The TTV is a stable heat source from which the user can make accurate power measurement, whereas processors can introduce additional factors that can impact test results. In particular, the power level from actual processors varies significantly, due to variances in the manufacturing process. The TTV provides consistent power and power density for thermal solution characterization and results can be easily translated to real processor performance.

Once the thermal solution is designed and validated with the TTV, it is strongly recommended to verify functionality of the thermal solution on real processors and on fully integrated systems.

Contact your Intel Field Sales representative for further information on the TTV or regarding accurate measurement of power dissipated by a processor.

### 3.3 Local Ambient Temperature Measurement Guidelines

The local ambient temperature  $T_A$  is the temperature of the ambient air surrounding the processor. For a passive heatsink,  $T_A$  is defined as the heatsink approaches air temperature; for an actively cooled heatsink, it is the temperature of inlet air to the active cooling fan.

It is worthwhile to determine the local ambient temperature in the chassis around the processor to understand the effect it may have on the case temperature.

$T_A$  is best measured by averaging temperature measurements at multiple locations in the heatsink inlet airflow. This method helps reduce error and eliminate minor spatial variations in temperature. The following guidelines are meant to enable accurate determination of the localized air temperature around the processor during system thermal testing.

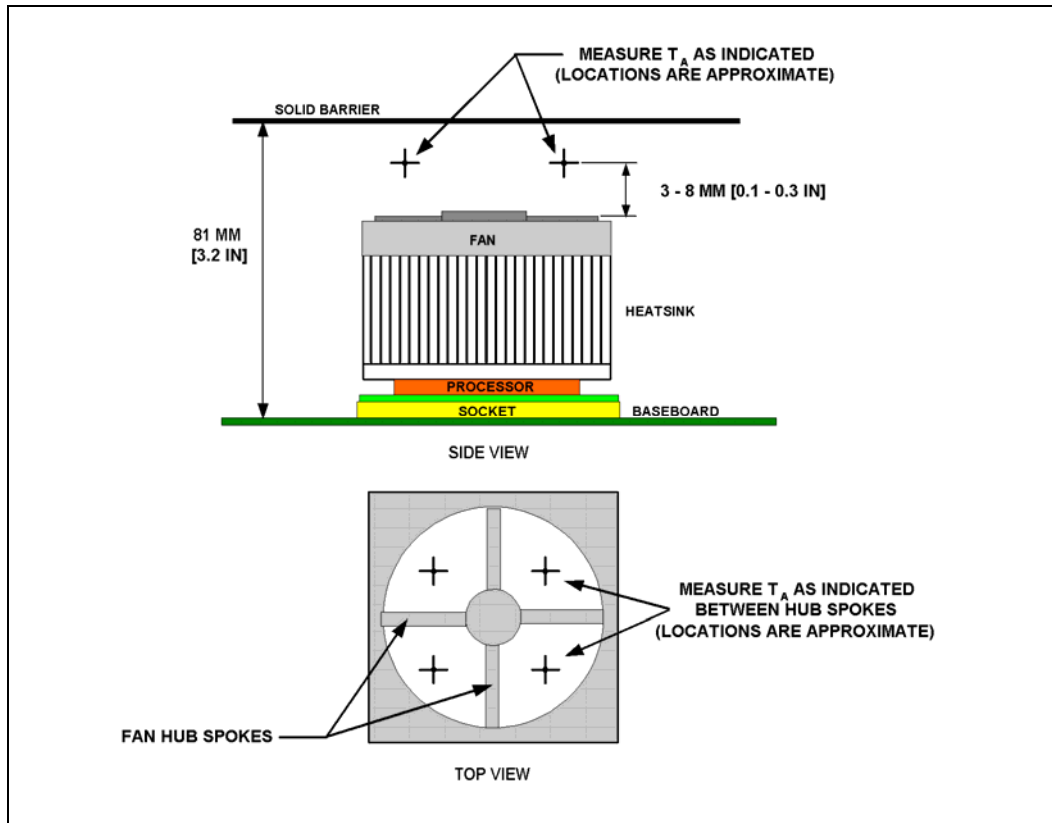


For **active heatsinks**, it is important to avoid taking measurement in the dead flow zone that usually develops above the fan hub and hub spokes. Measurements should be taken at four different locations uniformly placed at the center of the annulus formed by the fan hub and the fan housing to evaluate the uniformity of the air temperature at the fan inlet. The thermocouples should be placed approximately 3 mm to 8 mm [0.1 to 0.3 in] above the fan hub vertically and halfway between the fan hub and the fan housing horizontally as shown in Figure 5 (avoiding the hub spokes). Using an open bench to characterize an active heatsink can be useful, and usually ensures more uniform temperatures at the fan inlet. However, additional tests that include a solid barrier above the test motherboard surface can help evaluate the potential impact of the chassis. This barrier is typically clear Plexiglas\*, extending at least 100 mm [4 in] in all directions beyond the edge of the thermal solution. Typical distance from the motherboard to the barrier is 81 mm [3.2 in]. For even more realistic airflow, the motherboard should be populated with significant elements like memory cards, graphic card, and chipset heatsink. If a barrier is used, the thermocouple can be taped directly to the barrier with a clear tape at the horizontal location as previously described, half way between the fan hub and the fan housing. If a variable speed fan is used, it may be useful to add a thermocouple taped to the barrier above the location of the temperature sensor used by the fan to check its speed setting against air temperature. When measuring  $T_A$  in a chassis with a live motherboard, add-in cards, and other system components, it is likely that the  $T_A$  measurements will reveal a highly non-uniform temperature distribution across the inlet fan section.

For **passive heatsinks**, thermocouples should be placed approximately 13 mm to 25 mm [0.5 to 1.0 in] away from processor and heatsink as shown in Figure 6. The thermocouples should be placed approximately 51 mm [2.0 in] above the baseboard. This placement guideline is meant to minimize the effect of localized hot spots from baseboard components.

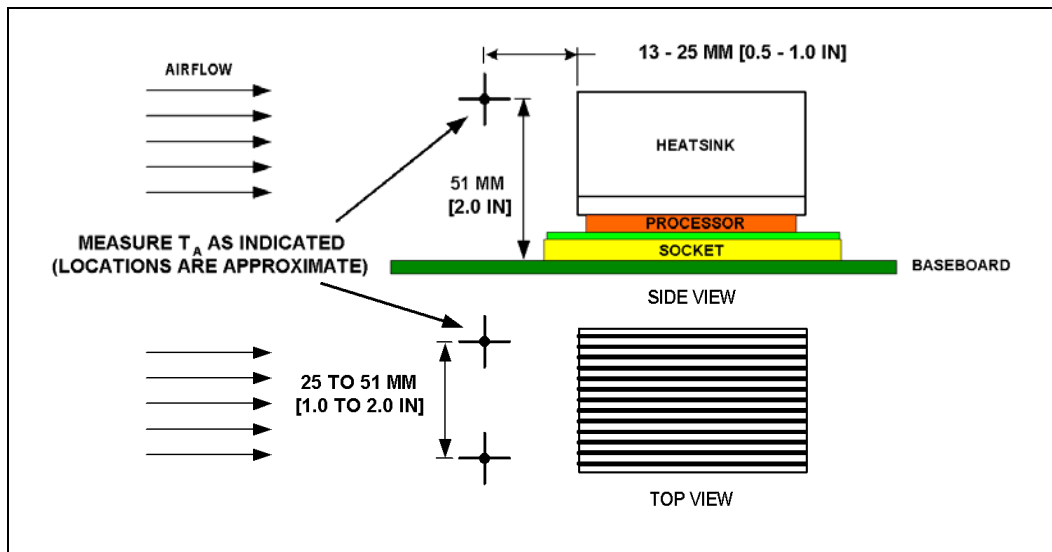
**Note:** Testing an active heatsink with a variable speed fan can be done in a thermal chamber to capture the worst-case thermal environment scenarios. Otherwise, when doing a bench top test at room temperature, the fan regulation prevents the heatsink from operating at its maximum capability. To characterize the heatsink capability in the worst-case environment in these conditions, it is then necessary to disable the fan regulation and power the fan directly, based on guidance from the fan supplier.

Figure 5. Locations for Measuring Local Ambient Temperature, Active Heatsink



NOTE: Drawing Not to Scale

Figure 6. Locations for Measuring Local Ambient Temperature, Passive Heatsink



NOTE: Drawing Not to Scale



### 3.4 Processor Case Temperature Measurement Guidelines

To ensure functionality and reliability, the processor is specified for proper operation when  $T_C$  is maintained at or below the thermal profile as listed in the datasheet. The measurement location for  $T_C$  is the geometric center of the IHS. Figure 2 shows the location for  $T_C$  measurement.

Special care is required when measuring  $T_C$  to ensure an accurate temperature measurement. Thermocouples are often used to measure  $T_C$ . Before any temperature measurements are made, the thermocouples must be calibrated, and the complete measurement system must be routinely checked against known standards. When measuring the temperature of a surface that is at a different temperature from the surrounding local ambient air, errors could be introduced in the measurements. The measurement errors could be caused by poor thermal contact between the junction of the thermocouple and the surface of the integrated heat spreader, heat loss by radiation, convection, by conduction through thermocouple leads, and/or by contact between the thermocouple cement and the heatsink base.

Appendix D defines a reference procedure for attaching a thermocouple to the IHS of a 775-Land LGA processor package for  $T_C$  measurement. This procedure takes into account the specific features of the 775-Land LGA package and of the LGA775 socket for which it is intended.

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## 4 Thermal Management Logic and Thermal Monitor Feature

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### 4.1 Processor Power Dissipation

An increase in processor operating frequency not only increases system performance, but also increases the processor power dissipation. The relationship between frequency and power is generalized in the following equation:  $P = CV^2F$  (where P = power, C = capacitance, V = voltage, F = frequency). From this equation, it is evident that power increases linearly with frequency and with the square of voltage. In the absence of power saving technologies, ever increasing frequencies will result in processors with power dissipations in the hundreds of watts. Fortunately, there are numerous ways to reduce the power consumption of a processor, and Intel is aggressively pursuing low power design techniques. For example, decreasing the operating voltage, reducing unnecessary transistor activity, and using more power efficient circuits can significantly reduce processor power consumption.

An on-die thermal management feature called Thermal Monitor is available on the processor. It provides a thermal management approach to support the continued increases in processor frequency and performance. By using a highly accurate on-die temperature sensing circuit and a fast acting Thermal Control Circuit (TCC), the processor can rapidly initiate thermal management control. The Thermal Monitor can reduce cooling solution cost, by allowing thermal designs to target TDP.

### 4.2 Thermal Monitor Implementation

The Thermal Monitor consists of the following components:

- A highly accurate on-die temperature sensing circuit.
- A bi-directional signal (PROCHOT#) that indicates if the processor has exceeded its maximum temperature or can be asserted externally to activate the Thermal Control Circuit (TCC) (see Section 4.2.1 for more details on user activation of TCC via PROCHOT# signal).
- FORCEPR# signal that will activate the TCC.
- A Thermal Control Circuit that will attempt to reduce processor temperature by rapidly reducing power consumption when the on-die temperature sensor indicates that it has exceeded the maximum operating point.
- Registers to determine the processor thermal status.



### 4.2.1 PROCHOT# Signal

The primary function of the PROCHOT# signal is to provide an external indication the processor has exceeded its maximum operating temperature. While PROCHOT# is asserted, the TCC will be active. Assertion of the PROCHOT# signal is independent of any register settings within the processor. It is asserted any time the processor die temperature reaches the trip point.

PROCHOT# can be configured via BIOS as an output or bi-directional signal. As an output, PROCHOT# will go active when the processor temperature of either core exceeds its maximum operating temperature. This indicates the TCC has been activated. As an input, assertion of PROCHOT# will activate the TCC for both cores. The TCC will remain active until the system de-asserts PROCHOT#.

If PROCHOT# is configured as an output only, the FORCEPR# signal can be driven from an external source to activate the TCC. This will prevent one core from asserting the PROCHOT# signal of the other core and unnecessarily activating the TCC of that core. Refer to Section 4.2.2 for details on the FORCEPR# signal.

The temperature at which the PROCHOT# signal goes active is individually calibrated during manufacturing. The power dissipation of each processor affects the set point temperature. The temperature where PROCHOT# goes active roughly parallels the thermal profile. Once configured, the processor temperature at which the PROCHOT# signal is asserted is not re-configurable.

One application is the thermal protection of voltage regulators (VR). System designers can create a circuit to monitor the VR temperature and activate the TCC when the temperature limit of the VR is reached. By asserting PROCHOT# (pulled-low) or FORCEPR#, which activates the TCC, the VR can cool down as a result of reduced processor power consumption. Bi-directional PROCHOT# can allow VR thermal designs to target maximum sustained current instead of maximum current. Systems should still provide proper cooling for the VR, and rely on bi-directional PROCHOT# signal only as a backup in case of system cooling failure.

**Note:** A thermal solution designed to meet the thermal profile targets should rarely experience activation of the TCC as indicated by the PROCHOT# signal going active.

### 4.2.2 FORCEPR# Signal

The FORCEPR# (force power reduction) input can be used by the platform to cause the processor (both cores) to activate the TCC. If the Thermal Monitor is enabled, the TCC will be activated upon the assertion of the FORCEPR# signal. The TCC will remain active until the system de-asserts FORCEPR#. FORCEPR# is an asynchronous input.

FORCEPR# can be used to thermally protect other system components. To use the VR as an example, when the FORCEPR# pin is asserted, the TCC circuit in the processor (both cores) will activate, reducing the current consumption of the processor and the corresponding temperature of the VR.

Note that assertion of the FORCEPR# does not automatically assert PROCHOT#. As mentioned previously, the PROCHOT# signal is asserted when a high temperature situation is detected. A minimum pulse width of 500  $\mu$ s is recommended when the FORCEPR# is asserted by the system. Sustained activation of the FORCEPR# pin may cause noticeable platform performance degradation.



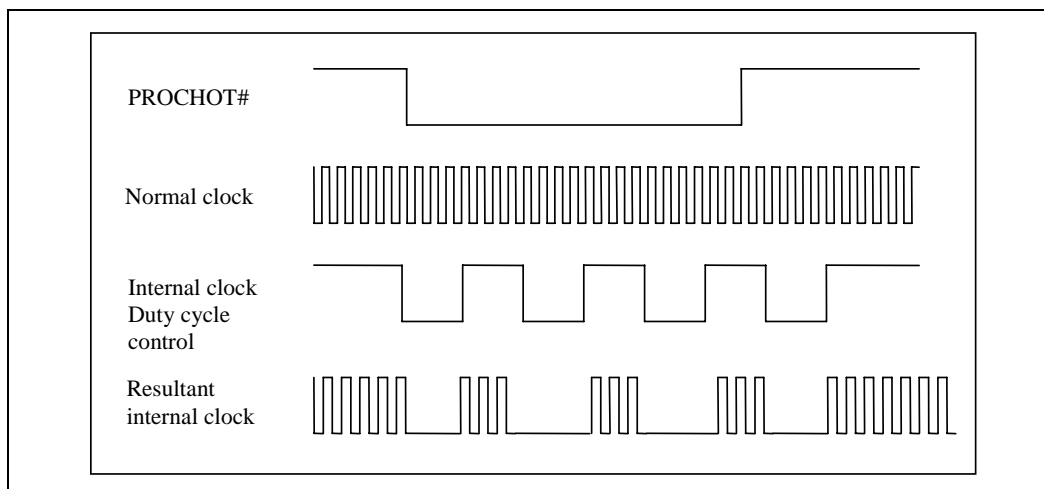
One application is the thermal protection of voltage regulators (VR). System designers can create a circuit to monitor the VR temperature and activate the TCC when the temperature limit of the VR is reached. By asserting FORCEPR# (pulled-low) and activating the TCC, the VR can cool down as a result of reduced processor power consumption. FORCEPR# can allow VR thermal designs to target maximum sustained current instead of maximum current. Systems should still provide proper cooling for the VR, and rely on FORCEPR# only as a backup in case of system cooling failure. The system thermal design should allow the power delivery circuitry to operate within its temperature specification even while the processor is operating at its Thermal Design Power. With a properly designed and characterized thermal solution, it is anticipated that FORCEPR# would only be asserted for very short periods of time when running the most power intensive applications. An under-designed thermal solution that is not able to prevent excessive assertion of FORCEPR# in the anticipated ambient environment may cause a noticeable performance loss. Refer to the appropriate platform design guide and the *Voltage Regulator-Down (VRD) 10.1 Design Guide for Desktop Socket 775* for details on implementing the FORCEPR# feature.

### 4.2.3 Thermal Control Circuit

The Thermal Control Circuit portion of the Thermal Monitor must be enabled for the processor to operate within specifications. The Thermal Monitor's TCC, when active, will attempt to lower the processor temperature by reducing the processor power consumption. In the original implementation of thermal monitor this is done by changing the duty cycle of the internal processor clocks, resulting in a lower effective frequency. When active, the TCC turns the processor clocks off and then back on with a predetermined duty cycle. The duty cycle is processor specific, and is fixed for a particular processor. The maximum time period the clocks are disabled is  $\sim 3 \mu\text{s}$ . This time period is frequency dependent and higher frequency processors will disable the internal clocks for a shorter time period. Figure 7 illustrates the relationship between the internal processor clocks and PROCHOT#.

Performance counter registers, status bits in model specific registers (MSRs), and the PROCHOT# output pin are available to monitor the Thermal Monitor behavior.

**Figure 7. Concept for Clocks under Thermal Monitor Control**





#### 4.2.4 Thermal Monitor 2

If enabled, the processor can support an enhanced Thermal Control Circuit. In conjunction with the existing Thermal Monitor logic, this capability is known as Thermal Monitor 2. This enhanced TCC provides an efficient means of reducing the power consumption within the processor and limiting the processor temperature.

Thermal Monitor 2 is only available for processors meeting the following conditions:

- Operating with a 533 MHz FSB and  $\geq 2.40$  GHz  
OR
- Operating with an 800 MHz FSB and  $\geq 3.60$  GHz

When Thermal Monitor 2 is enabled, and a high temperature situation is detected, the enhanced TCC will be activated. The enhanced TCC causes the processor to adjust its operating frequency (by dropping the bus-to-core multiplier to its minimum available value) and input voltage identification (VID) value. This combination of reduced frequency and VID results in a reduction in processor power consumption.

A processor enabled for Thermal Monitor 2 includes two operating points, each consisting of a specific operating frequency and voltage. The first operating point represents the normal operating condition for the processor.

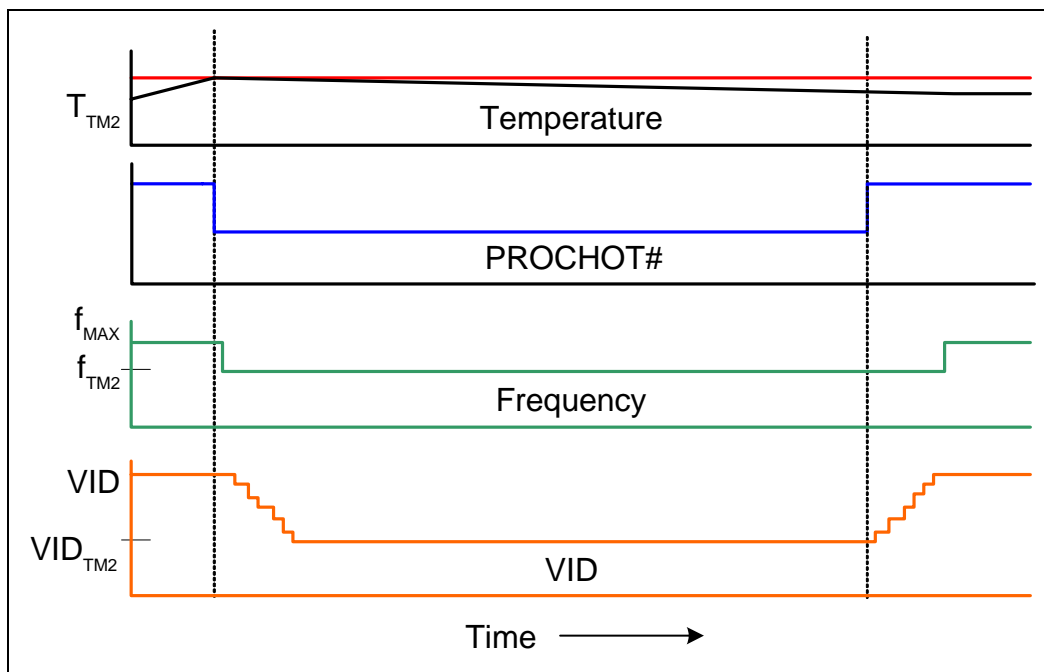
The second operating point consists of both a lower operating frequency and voltage. When the TCC is activated, the processor automatically transitions to the new frequency. This transition occurs very rapidly (on the order of 5 microseconds). During the frequency transition, the processor is unable to service any bus requests, all bus traffic is blocked. Edge-triggered interrupts will be latched and kept pending until the processor resumes operation at the new frequency.

Once the new operating frequency is engaged, the processor will transition to the new core operating voltage by issuing a new VID code to the voltage regulator. The voltage regulator must support VID transitions in order to support Thermal Monitor 2. During the voltage change, it will be necessary to transition through multiple VID codes to reach the target operating voltage. Each step will be one VID table entry (i.e., 12.5 mV steps). The processor continues to execute instructions during the voltage transition. Operation at the lower voltage reduces the power consumption of the processor, providing a temperature reduction.

Once the processor has sufficiently cooled, and a minimum activation time has expired, the operating frequency and voltage transition back to the normal system operating point. Transition of the VID code will occur first to insure proper operation once the processor reaches its normal operating frequency. Refer to Figure 8 for an illustration of this ordering.



Figure 8. Thermal Monitor 2 Frequency and Voltage Ordering



Refer to the datasheet for further information on Thermal Monitor 2.

#### 4.2.5 Operation and Configuration

To maintain compatibility with previous generations of processors that have no integrated thermal logic, the Thermal Control Circuit portion of Thermal Monitor is disabled by default. During the boot process, the BIOS must enable the Thermal Control Circuit. **Thermal Monitor must be enabled to ensure proper processor operation.**

The Thermal Control Circuit feature can be configured and monitored in a number of ways. OEMs are required to enable the Thermal Control Circuit while using various registers and outputs to monitor the processor thermal status. The Thermal Control Circuit is enabled by the BIOS setting a bit in an MSR (Model Specific Register). Enabling the Thermal Control Circuit allows the processor to attempt to maintain a safe operating temperature without the need for special software drivers or interrupt handling routines. When the Thermal Control Circuit has been enabled, processor power consumption will be reduced after the thermal sensor detects a high temperature (i.e., PROCHOT# assertion). The Thermal Control Circuit and PROCHOT# transitions to inactive once the temperature has been reduced below the thermal trip point, although a small time-based hysteresis has been included to prevent multiple PROCHOT# transitions around the trip point. External hardware can monitor PROCHOT# and generate an interrupt when there is a transition from active-to-inactive or inactive-to-active. PROCHOT# can also be configured to generate an internal interrupt that would initiate an OEM supplied interrupt service routine. Regardless of the configuration selected, PROCHOT# will always indicate the thermal status of the processor.



The power reduction mechanism of thermal monitor can also be activated manually using an “on-demand” mode. Refer to Section 4.2.6 for details on this feature.

#### 4.2.6 On-Demand Mode

For testing purposes, the thermal control circuit may also be activated by setting bits in the ACPI MSRs. The MSRs may be set based on a particular system event (e.g., an interrupt generated after a system event), or may be set at any time through the operating system or custom driver control thus forcing the thermal control circuit on. This is referred to as “on-demand” mode. Activating the thermal control circuit may be useful for thermal solution investigations or for performance implication studies. When using the MSRs to activate the on-demand clock modulation feature, the duty cycle is configurable in steps of 12.5%, from 12.5% to 87.5%.

For any duty cycle, the maximum time period the clocks are disabled is  $\sim 3 \mu\text{s}$ . This time period is frequency dependent, and decreases as frequency increases. To achieve different duty cycles, the length of time that the clocks are disabled remains constant, and the time period that the clocks are enabled is adjusted to achieve the desired ratio. For example, if the clock disable period is  $3 \mu\text{s}$ , and a duty cycle of  $\frac{1}{4}$  (25%) is selected, the clock on time would be reduced to approximately  $1 \mu\text{s}$  [on time ( $1 \mu\text{s}$ )  $\div$  total cycle time ( $3 + 1 \mu\text{s}$ ) =  $\frac{1}{4}$  duty cycle]. Similarly, for a duty cycle of  $\frac{7}{8}$  (87.5%), the clock on time would be extended to  $21 \mu\text{s}$  [ $21 \div (21 + 3) = \frac{7}{8}$  duty cycle].

In a high temperature situation, if the thermal control circuit and ACPI MSRs (automatic and on-demand modes) are used simultaneously, the fixed duty cycle determined by automatic mode would take precedence.

**Note:** On-demand mode can not activate the power reduction mechanism of Thermal Monitor 2.

#### 4.2.7 System Considerations

Intel requires the Thermal Monitor and Thermal Control Circuit to be enabled for all processors. The thermal control circuit is intended to protect against short term thermal excursions that exceed the capability of a properly designed processor thermal solution. Thermal Monitor should not be relied upon to compensate for a thermal solution that does not meet the thermal profile up to the thermal design power (TDP).

Each application program has its own unique power profile, although the profile has some variability due to loop decisions, I/O activity, and interrupts. In general, compute intensive applications with a high cache hit rate dissipate more processor power than applications that are I/O intensive or have low cache hit rates.

The processor TDP is based on measurements of processor power consumption while running various high power applications. This data is used to determine those applications that are interesting from a power perspective. These applications are then evaluated in a controlled thermal environment to determine their sensitivity to activation of the thermal control circuit. This data is used to derive the TDP targets published in the processor datasheet.

A system designed to meet the thermal profile at TDP and  $T_{C-MAX}$  values published in the processor datasheet greatly reduces the probability of real applications causing the



thermal control circuit to activate under normal operating conditions. Systems that do not meet these specifications could be subject to more frequent activation of the thermal control circuit depending upon ambient air temperature and application power profile. Moreover, if a system is significantly under designed, there is a risk that the Thermal Monitor feature will not be capable of maintaining a safe operating temperature and the processor could shutdown and signal THERMTRIP#.

For information regarding THERMTRIP#, refer to the processor datasheet and to Section 4.2.9.3 of this Thermal Design Guidelines.

#### **4.2.8 Operating System and Application Software Considerations**

The Thermal Monitor feature and its thermal control circuit work seamlessly with ACPI compliant operating systems. The Thermal Monitor feature is transparent to application software since the processor bus snooping, ACPI timer, and interrupts are active at all times.

#### **4.2.9 On-Die Thermal Diode**

There are two independent thermal sensing devices in the processor. One is the on-die thermal diode and the other is in the temperature sensor used for the Thermal Monitor (and Thermal Monitor 2) and for THERMTRIP#. The Thermal Monitor's temperature sensor and the on-die thermal diode are independent and physically isolated devices. Circuit constraints and performance requirements prevent the Thermal Monitor's temperature sensor and the on-die thermal diode from being located at the same place on the silicon. The temperature distribution across the die may result in significant temperature differences between the on-die thermal diode and the Thermal Monitor's temperature sensor. This temperature variability across the die is highly dependent on the application being run. As a result, it is not possible to predict the activation of the thermal control circuit by monitoring the on-die thermal diode.

System integrators should note that there is no defined correlation between the on-die thermal diode and the processor case temperature. The temperature distribution across the die is affected by the power being dissipated, type of activity the processor is performing e.g. integer or floating point intensive and the leakage current. The dynamic and independent nature of these effects makes it difficult to provide a meaningful correlation for the processor population.

System integrators that plan on using the thermal diode for system or component level fan control to optimize acoustics need to refer to Acoustic Fan Control, Section 6.1.



#### 4.2.9.1 Reading the On-Die Thermal Diode Interface

The on-die thermal diode is accessible from a pair of pins on the processor. The fan speed controller remote thermal sense signals should be connected to these pins per the vendor's recommended layout guidelines.

The processor datasheet documents two sets of diode parameters for the hardware monitor device vendors to use in measuring the on-die thermal diode. The first and original set of parameters is based on the diode equation model. The second set of parameters is based on the transistor equation model. In either case the connection is through the same pins documented in Table 2.

Table 2. Thermal Diode Interface

Pin Name	Pin Number	Pin Description
THERMDA	AL1	Diode anode
THERMDC	AK1	Diode cathode

#### 4.2.9.2 Correction Factors for the On-Die Thermal Diode

A number of issues can affect the accuracy of the temperature reported by thermal diode sensors. These include the diode ideality and the series resistance that are characteristics of the processor on-die thermal diode. The processor datasheet provides the specification for these parameters. The trace layout recommendations between the thermal diode sensors and the processor socket should be followed as listed in the vendor datasheets. The design characteristics and usage models of the thermal diode sensors should be reviewed in the datasheets available from the manufacturers.

The choice of a remote diode sensor measurement component has a significant impact to the accuracy of the reported on-die diode temperature. The component vendors offer components that have stated accuracy of  $\pm 3^\circ\text{C}$  to  $\pm 1^\circ\text{C}$ . The improved accuracy generally comes from the number of times a current is passed through the diode and the ratios of the currents for those devices using the diode equation model. A device that uses the transistor model and equations can provide improved accuracy when the diode ideality factor is close to the maximum or minimum limits from the processor datasheet. Consult the vendor datasheet for details on their measurement process and stated accuracy.

The ideality factor,  $n$ , represents the deviation from ideal diode behavior as exemplified by the diode equation:

$$I_{FW} = I_S * (E^{qVD/nkT} - 1)$$

Where  $I_{FW}$  = forward bias current,  $I_S$  = saturation current,  $q$  = electronic charge,  $V$  = voltage across the diode,  $k$  = Boltzmann Constant and  $T$  = absolute temperature (Kelvin). This equation determines the ideality factor of an individual diode.





To determine a correction factor to use with the thermal sensor, the ideality equation can be simplified to the following:

$$T_{\text{ERROR}} = T_{\text{MEASURED}} * (1 - N_{\text{ACTUAL}} / N_{\text{TRIM}})$$

Where  $T_{\text{ERROR}}$  = correction factor to add to the reported temperature,  $T_{\text{MEASURED}}$  = temperature reported by the thermal sensor (Kelvin),  $N_{\text{ACTUAL}}$  = the ideality of the on-die thermal diode,  $N_{\text{TRIM}}$  = the assumed ideality used by the thermal sensor. For the range of temperatures where the thermal diode is being measured, 30–80 °C, this error term is nearly constant.

The value of  $N_{\text{TRIM}}$  is available from the datasheet of the device measuring the processor on die thermal diode.  $N_{\text{ACTUAL}}$  can be assumed to be typical for this equation.

The series resistance,  $R_T$ , is provided to allow for a more accurate measurement of the on-die thermal diode temperature.  $R_T$ , as defined, includes the lands and processor package but does not include any socket resistance or board trace resistance between the socket and the external remote diode thermal sensor.  $R_T$  can be used by remote diode thermal sensors with a register that can add the offset. Some vendors offer a feature that automatically cancels the series resistance. To manually calculate the use the following equation:

$$T_{\text{error}} = (R_T * (N - 1) * I_{\text{FWmin}}) / (nk/q * I_N \ln N)$$

Where  $T_{\text{ERROR}}$  = sensor temperature error,  $N$  = sensor current ratio,  $k$  = Boltzmann Constant,  $q$  = electronic charge.

The transistor model uses the equation for the collector current and the  $nQ$  representing the deviation from an ideal transistor and is shown in the following:

$$I_C = I_S * e^{qV_{be}/nQkT - 1}$$

Where  $I_S$  = saturation current,  $q$  = electronic charge,  $V_{be}$  – voltage across the transistor base emitter junction (same nodes as VD),  $k$  = Boltzmann Constant and  $T$  = temperature (Kelvin). The series resistance error for a device using the transistor model can be calculated using the  $T_{\text{error}}$  equation.

#### 4.2.9.3 Thermal Diode Correction Factor

The Pentium D processor 900 sequence, Pentium processor Extreme Edition 955, 965, and Pentium 4 processor 6x1 sequence have a MSR that contains thermal diode error data, called Thermal Diode Offset. This was added to provide a method for improving the accuracy of hardware monitor components that use the diode model for measuring the on-die thermal diode. Hardware monitor devices that use the transistor model for determining the processor temperature can ignore this register. The value of this MSR is added to the Thermal Diode Base value from the datasheet. This calculation is done by the BIOS during power on similar to the calculation of  $T_{\text{CONTROL}}$ . See the appropriate processor datasheet for further details on reading the register and calculating the Thermal Diode Correction Factor.

To calculate the Thermal Diode Offset a  $N_{\text{TRIM}}$  value was assumed and is listed in the processor datasheet. Each hardware monitor device assumes a  $N_{\text{TRIM}}$  value for



calculating  $T_{\text{ERROR}}$ . If the value used by the hardware monitor device is significantly different from the  $N_{\text{TRIM}}$  value in the datasheet, then it may be beneficial to calculate the processor  $N_{\text{ACTUAL}}$  using the  $T_{\text{ERROR}}$  equation in Section 4.2.9.2.

The Thermal Diode Correction Factor can be used in the fan speed control component in two methods. For hardware monitor components that provide a register to correct fixed temperature errors, this value should be programmed into that register. Once programmed, the hardware monitor will add this value to the measured  $T_{\text{DIODE}}$  and the fan speed will be adjusted based on this corrected temperature.

For those hardware monitor components that do not provide a register to correct fixed temperature errors, a different approach is required. All target temperatures will be adjusted by the value of  $T_{\text{DIODE\_CORRECTION}}$ . The result is to shift the fan speed control set points to account for the fixed measurement error. See Chapter 6 and Appendix E for details on how to implement this in a fan speed control design.

This method will also impact applications that display processor temperatures to the end user such as diagnostics pages in BIOS. If the  $T_{\text{DIODE\_CORRECTION}}$  is not applied to these applications or displays, the end user may have questions.

#### 4.2.10 THERMTRIP# Signal

In the event of a catastrophic cooling failure, the processor will automatically shut down when the silicon temperature has reached its operating limit. At this point, the system bus signal THERMTRIP# goes active and power must be removed from the processor. THERMTRIP# activation is independent of processor activity and does not generate any bus cycles. Refer to the processor datasheet for more information about THERMTRIP#.

The temperature where the THERMTRIP# signal goes active is individually calibrated during manufacturing. The temperature where THERMTRIP# goes active is roughly parallel to the thermal profile and greater than the PROCHOT# activation temperature. Once configured, the temperature at which the THERMTRIP# signal is asserted is neither re-configurable nor accessible to the system.

#### 4.2.11 Cooling System Failure Warning

It may be useful to use the PROCHOT# signal as an indication of cooling system failure. Messages could be sent to the system administrator to warn of the cooling failure, while the thermal control circuit would allow the system to continue functioning or allow a normal system shutdown. If no thermal management action is taken, the silicon temperature may exceed the operating limits, causing THERMTRIP# to activate and shut down the processor. Regardless of the system design requirements or thermal solution ability, the Thermal Monitor feature must still be enabled to ensure proper processor operation.



## 5 Intel® Thermal/Mechanical Reference Design Information

### 5.1 ATX Heatsink Performance Targets

Table 3 provides the heatsink performance targets for the processors covered by this document.

The table also includes the ambient assumption,  $T_A$ , for the Intel reference thermal solution at the processor fan heatsink inlet as discussed in Section 3.3. An external ambient temperature to the chassis of 35 °C is assumed, resulting in a temperature rise,  $T_R$ , of 4 °C for solutions supporting 775\_VR\_CONFIG\_05B processors. Meeting  $T_A$  and  $\Psi_{CA}$  targets can maximize processor performance (refer to Sections 2.2, 2.4, and Chapter 4). By minimizing  $T_R$ , in the performance chassis this helps lead to improved acoustics.

Refer to the datasheet for detailed processor thermal specifications.

**Table 3. ATX Heatsink Performance Targets**

Processor	Target Thermal Performance, $\Psi_{CA}$ (Mean + 3 $\sigma$ )	$T_A$ Assumption	Notes
Intel Pentium D processor 800 sequence and Intel Pentium processor Extreme Edition 840 775_VR_CONFIG_05B processors (130 W TDP)	0.24 °C/W	$T_A = 39\text{ °C}$	
Intel Pentium D 900 processors and Intel Pentium processor Extreme Edition 955 and 965 775_VR_CONFIG_05B processors (130 W TDP)	0.23 °C/W	$T_A = 39\text{ °C}$	
Intel Core™2 Duo Extreme processor X6800 775_VR_CONFIG_05B processors (75 W TDP)	0.27 °C/W	$T_A = 40\text{ °C}$	1
Intel Pentium D processor 800 sequence 775_VR_CONFIG_05A processors (95 W TDP)	0.25 °C/W	$T_A = 40\text{ °C}$	1
Intel Pentium D processor 900 sequence 775_VR_CONFIG_05A (95 W TDP)	0.24 °C/W	$T_A = 40\text{ °C}$	1
Intel Pentium 4 processor 6x1 sequence 775_VR_CONFIG_05A (86 W TDP)	0.34 °C/W	$T_A = 40\text{ °C}$	1

**NOTES:**

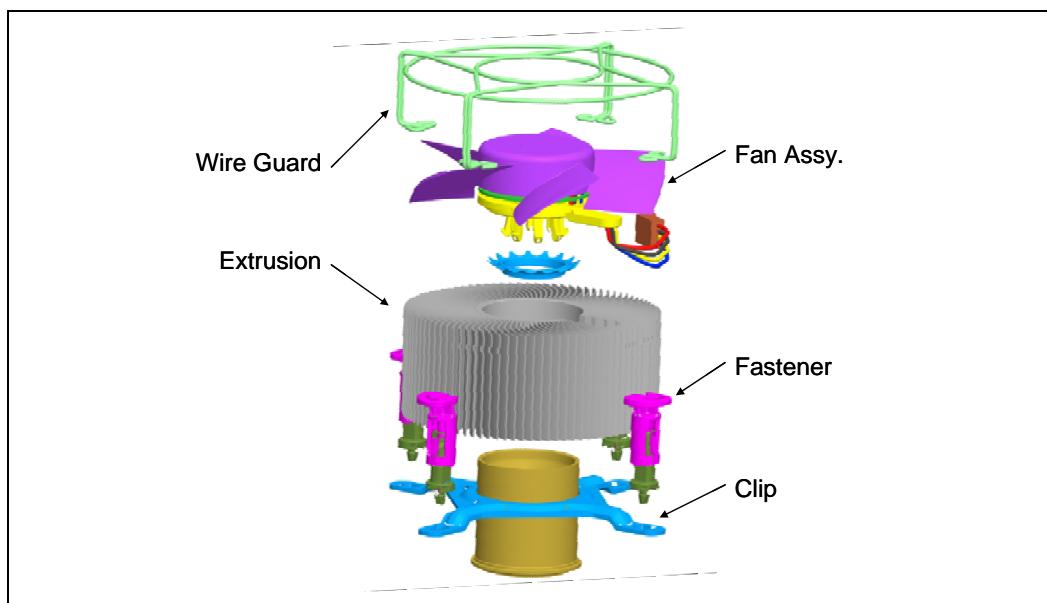
- Thermal solutions to support the 775\_VR\_CONFIG\_05A processors (TDP=95 W or 86 W) are expected to be able to reuse designs supporting 775\_VR\_CONFIG\_04B processors. For detailed information on the Intel reference solution, RCBFH-3, refer to the *Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal and Mechanical Design Guidelines*, available at:  
<http://www.intel.com/design/Pentium4/guides/302553.htm>

## 5.2 Results for the ATX Reference Design

The reference thermal solution is an active air-cooled design, with a fan installed at the top of the heatsink. This solution is called the Intel Radial Curved Fin Heatsink Reference Design (Intel RCFH-4 Reference Design). The solution comes as an integrated assembly, an exploded view of the assembly is provided in Figure 9.

The reference solution is compliant with the reference ATX motherboard keep-out and height recommendations defined in Section 5.6.

**Figure 9. Intel® RCFH-4 Reference Design (Exploded View)**



Development vendor information for the Intel RCFH-4 Reference Solution is provided in Appendix H.

**Note:** If this fan design is used in your product and you will deliver it to end use customers, you have the responsibility to determine an adequate level of protection (e.g., protection barriers, a cage, or an interlock) against contact with the energized fan by the user during user servicing.



## 5.2.1 Reference Heatsink Performance

Table 4 provides the RCFH-4 performance for the Pentium D and Pentium processor Extreme Edition 840. The results are based on the test procedure described in Section 5.2.4.

The table also includes a  $T_A$  assumption of 39 °C for the Intel reference thermal solution at the processor fan heatsink inlet discussed in Section 3.3. An external ambient temperature to the chassis of 35 °C is assumed, resulting in a temperature rise,  $T_R$ , of 4 °C. Meeting  $T_A$  and  $\Psi_{CA}$  targets can maximize processor performance (refer to Sections 2.2, 2.4, and Chapter 4). Minimizing  $T_R$  can lead to improved acoustics.

**Table 4. ATX Reference Heatsink (RCFH-4) Performance for 775\_VR\_CONFIG\_05B Processors**

Processor	Measured Thermal Performance, $\Psi_{ca}$ (Mean + 3 $\sigma$ )	$T_A$ Assumption
Intel® Pentium® processor Extreme Edition 840	0.23 °C/W	$T_A = 39\text{ °C}$
Intel® Pentium® D processor	0.23 °C/W	$T_A = 39\text{ °C}$

## 5.2.2 Acoustics

To optimize acoustic emission by the fan heatsink assembly, the reference design implements a variable speed fan controlled by a thermistor. A variable speed fan allows higher thermal performance at higher fan inlet temperatures ( $T_A$ ) and lower thermal performance with improved acoustics at lower fan inlet temperatures.

**Table 5. Acoustic Results**

Fan Speed RPM	Thermistor Set Point	Acoustic	Thermal Performance $\Psi_{ca}$	Notes
5100	High $T_A \geq 38\text{ °C}$	6.6 BA	0.23 °C/W	2
1900	Low $T_A \leq 28$	4.2 BA	0.32 °C/W	2
1000	Low	3.5 BA	0.44 °C/W	1,2

**NOTES:**

1. Minimum fan speed allowed by fan design. In the reference design, the Fan Speed Control component would drive the PWM signal to the minimum duty cycle.
2. Acoustic performance is defined in terms of measured sound power (LWA) as defined in ISO 9296 standard, and measured according to ISO 7779.

While the fan hub thermistor helps optimize acoustics at high processor workloads by adapting the maximum fan speed to support the processor thermal profile, additional acoustic improvements can be achieved at lower processor workload by using the  $T_{CONTROL}$  specifications described in Section 2.2.3. Intel's recommendation is to use the *Fan Specification for 4 Wire PWM Controlled Fans* to implement fan speed control capability based on-die thermal diode temperature. Refer to Chapter 6 for further details.



### 5.2.3 Altitude

The reference heatsink solutions will be evaluated at sea level. However, many companies design products that must function reliably at high altitude, typically 1,500 m [5,000 ft] or more. Air-cooled temperature calculations and measurements at sea level must be adjusted to take into account altitude effects like variation in air density and overall heat capacity. This often leads to some degradation in thermal solution performance compared to what is obtained at sea level, with lower fan performance and higher surface temperatures. The system designer needs to account for altitude effects in the overall system thermal design to make sure that the  $T_c$  requirement for the processor is met at the targeted altitude.

### 5.2.4 Reference Heatsink Thermal Validation

The Intel reference heatsink was validated within specific boundary conditions based on the methodology described in Section 5.3.

Testing is done on bench top test boards at ambient lab temperature. In particular, for the reference heatsink, the Plexiglas\* barrier is installed 81.28 mm [3.2 in] above the motherboard (refer to Section 3.3).

The test results, for a number of samples, are reported in terms of a worst-case mean +  $3\sigma$  value for thermal characterization parameter using actual processors.

**Note:** The above 81.28 mm obstruction height that is used for testing complies with the recommended obstruction height of 88.9 mm for the ATX form factor. However, it would not be sufficient for systems in strict compliance with the ATX specification which allows an obstruction as low as 76.2 mm above the motherboard surface in Area A.



## 5.2.5 Fan Performance for Active Heatsink Thermal Solution

The fan power requirements for proper operation are provided in Table 6.

**Table 6. Fan Electrical Performance Requirements**

Requirement	Value
Maxium fan current draw	1.5 A
Fan start-up current draw	2.2 A
Fan start-up current draw maximum duration	1.0 second
Fan header voltage	12 V $\pm$ 5%
Tachometer output	2 pulse per revolution

In addition, to comply with overall thermal requirements (Section 5.2.1) and the general environmental reliability requirements (Section 5.3), the fan should meet the following performance requirements:

- Mechanical wear out represents the highest risk reliability parameter for fans. The capability of the functional mechanical elements (ball bearing, shaft, and tower assembly) must be demonstrated to a minimum useful lifetime of 50,000 hours.
- In addition to passing the environmental reliability tests described in Section 5.3, the fan must demonstrate adequate performance after 7,500 on/off cycles with each cycle specified as 3 minutes on, 2 minutes off, at a temperature of 70 °C.

See the *Fan Specification for 4-wire PWM Controlled Fans* for additional details on the fan specification.

## 5.3 Environmental Reliability Testing

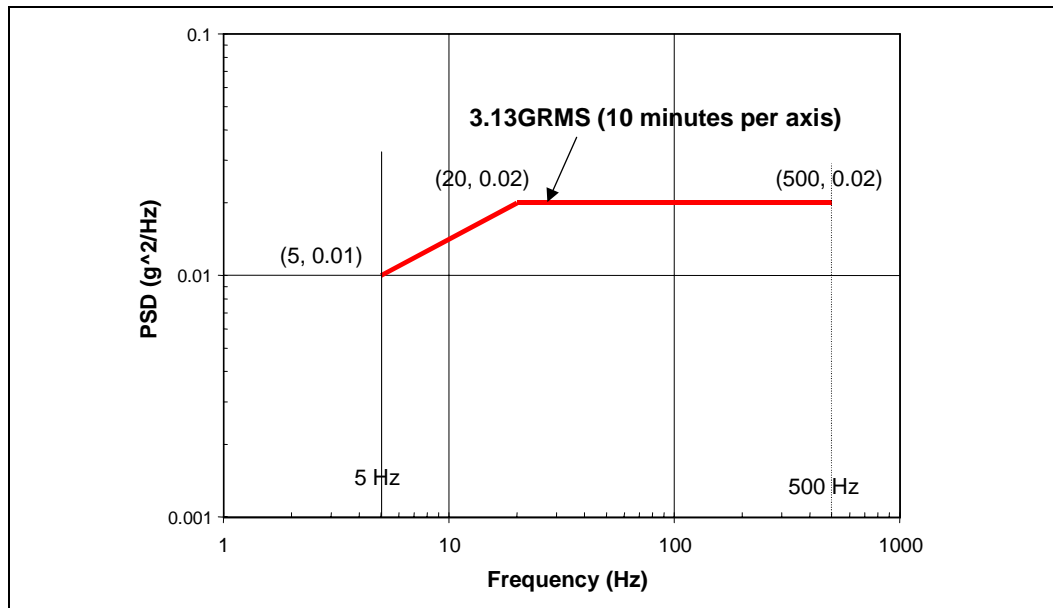
### 5.3.1 Structural Reliability Testing

Structural reliability tests consist of unpackaged, board-level vibration and shock tests of a given thermal solution in the assembled state. The thermal solution should meet the specified thermal performance targets after these tests are conducted; however, the test conditions outlined here may differ from your own system requirements.

#### 5.3.1.1 Random Vibration Test Procedure

- Duration: 10 min/axis, 3 axes
- Frequency Range: 5 Hz to 500 Hz
- Power Spectral Density (PSD) Profile: 3.13 G RMS

Figure 10. Random Vibration PSD

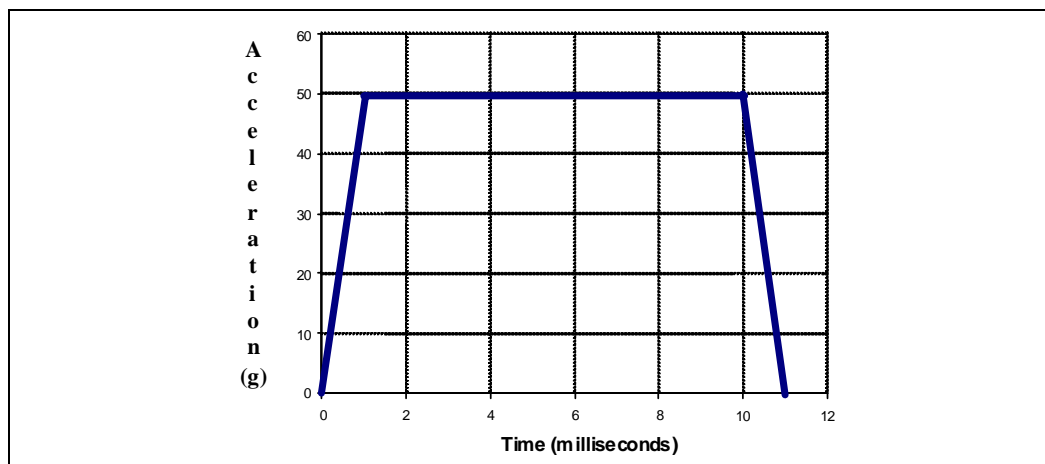


#### 5.3.1.2 Shock Test Procedure

Recommended performance requirement for a motherboard:

- Quantity: 3 drops for + and - directions in each of 3 perpendicular axes (i.e., total 18 drops).
- Profile: 50 G trapezoidal waveform, 11 ms duration, 170 in/sec minimum velocity change.
- Setup: Mount sample board on test fixture.



**Figure 11. Shock Acceleration Curve**

#### 5.3.1.2.1 Recommended Test Sequence

Each test sequence should start with components (i.e., motherboard, heatsink assembly, etc.) that have not been previously submitted to any reliability testing. The test sequence should always start with a visual inspection after assembly, and BIOS/Processor/Memory test (refer to Section 5.3.3).

Prior to the mechanical shock and vibration test, the units under test should be preconditioned for 72 hours at 45 °C. The purpose is to account for load relaxation during burn in stage.

The stress test should be followed by a visual inspection and then BIOS/Processor/Memory test.

#### 5.3.1.2.2 Post-Test Pass Criteria

The post-test pass criteria are:

1. No significant physical damage to the heatsink attach mechanism (including such items as clip and motherboard fasteners).
2. Heatsink must remain attached to the motherboard.
3. Heatsink remains seated and its bottom remains mated flatly against IHS surface. No visible gap between the heatsink base and processor IHS. No visible tilt of the heatsink with respect to its attach mechanism.
4. No signs of physical damage on motherboard surface due to impact of heatsink or heatsink attach mechanism.
5. No visible physical damage to the processor package.
6. Successful BIOS/Processor/memory test of post-test samples.
7. Thermal compliance testing to demonstrate that the case temperature specification can be met.



### 5.3.2 Power Cycling

Thermal performance degradation due to TIM degradation is evaluated using power cycling testing. The test is defined by 7500 cycles for the case temperature from room temperature (~23 °C) to the maximum case temperature defined by the thermal profile at TDP. The Thermal Test Vehicle (refer to Section 3.2) is used for this test.

### 5.3.3 Recommended BIOS/Processor/Memory Test Procedures

This test is to ensure proper operation of the product before and after environmental stresses, with the thermal mechanical enabling components assembled. The test shall be conducted on a fully operational motherboard that has not been exposed to any testing prior to the test being considered.

Testing setup should include the following components, properly assembled and/or connected:

- Appropriate system motherboard
- Processor
- All enabling components, including socket and thermal solution parts
- Power supply
- Disk drive
- Video card
- DIMM
- Keyboard
- Monitor

The pass criterion is that the system under test shall successfully complete the checking of BIOS, basic processor functions and memory, without any errors.

## 5.4 Material and Recycling Requirements

Material shall be resistant to fungal growth. Examples of non-resistant materials include cellulose materials, animal and vegetable based adhesives, grease, oils, and many hydrocarbons. Synthetic materials such as PVC formulations, certain polyurethane compositions (e.g., polyester and some polyethers), plastics which contain organic fillers of laminating materials, paints, and varnishes also are susceptible to fungal growth. If materials are not fungal growth resistant, then MIL-STD-810E, Method 508.4 must be performed to determine material performance.

Material used shall not have deformation or degradation in a temperature life test.

Any plastic component exceeding 25 grams must be recyclable per the European Blue Angel recycling standards.



## 5.5 Safety Requirements

Heatsink and attachment assemblies shall be consistent with the manufacture of units that meet the following safety standards:

- UL Recognition-approved for flammability at the system level. All mechanical and thermal enabling components must be a minimum UL94V-2 approved.
- CSA Certification. All mechanical and thermal enabling components must have CSA certification.
- All components (in particular the heatsink fins) must meet the test requirements of UL1439 for sharp edges.
- If the International Accessibility Probe specified in IEC 950 can access the moving parts of the fan, consider adding safety feature so that there is no risk of personal injury.

## 5.6 Geometric Envelope for Intel Reference ATX Thermal Mechanical Design

Figure 57, Figure 58, and Figure 59 in Appendix G gives detailed reference ATX/μATX motherboard keep-out information for the reference thermal/mechanical enabling design. These drawings include height restrictions in the enabling component region.

The maximum height of the reference solution above the motherboard is 71.12 mm [2.8 inches], and is compliant with the motherboard primary side height constraints defined in the *ATX Specification revision 2.1* and the *microATX Motherboard Interface Specification revision 1.1* found at <http://www.formfactors.org>. The reference solution requires a chassis obstruction height of at least 81.28 mm [3.2 inches], measured from the top of the motherboard (refer to Sections 3.3 and 5.2.4). This allows for appropriate fan inlet airflow to ensure fan performance, and therefore overall cooling solution performance. This is compliant with the recommendations found in both *ATX Specification V2.1* and *microATX Motherboard Interface Specification V1.1* documents.

Figure 60 through Figure 64 provides the motherboard keep-out information for the BTX thermal mechanical solutions. Additional information on BTX design considerations is in the *Balanced Technology Extended (BTX) System Design Guide* available at <http://www.formfactors.org>.

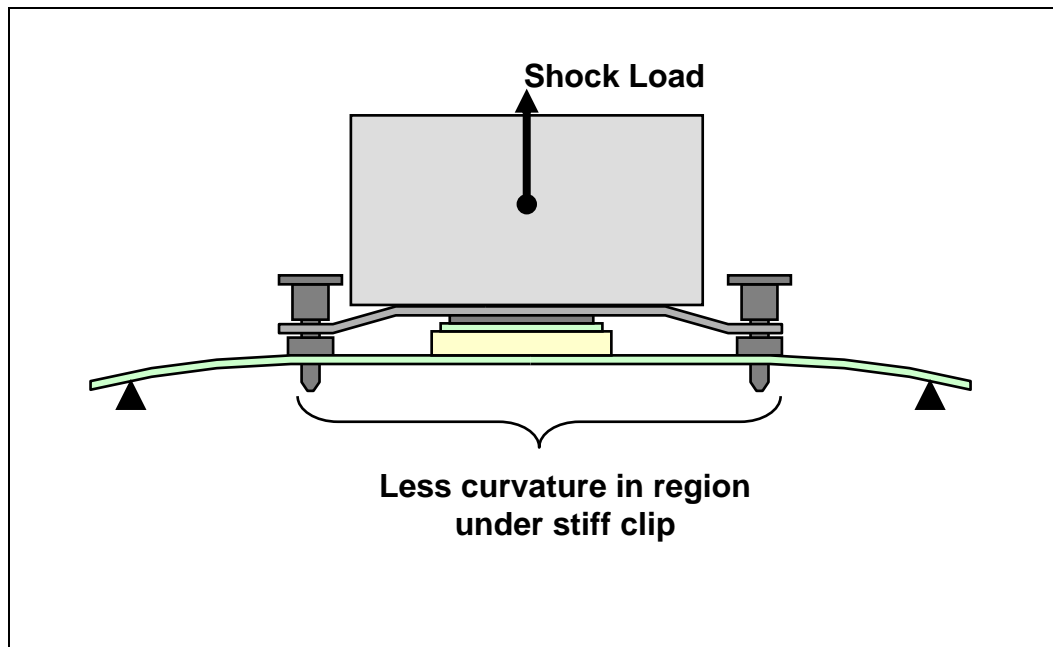
## 5.7 Reference Attach Mechanism

### 5.7.1 Structural Design Strategy

Structural design strategy for the Intel RCFH-4 Reference Solution is to minimize upward board deflection during shock to help protect the LGA775 socket.

The reference design uses a high clip stiffness that resists local board curvature under the heatsink, and minimizes, in particular, upward board deflection (Figure 12). In addition, a moderate preload provides initial downward deflection.

**Figure 12. Upward Board Deflection during Shock**



The target metal clip nominal stiffness is 540 N/mm [3100 lb/in]. The combined target for reference clip and fasteners nominal stiffness is 380 N/mm [2180 lb/in]. This is consistent with the results for the RCBFH-3 design. The nominal preload provided by the Intel RCFH-4 reference design is 191.3 N  $\pm$  44.5 N [43 lb  $\pm$  10 lb].

**Note:** Intel reserves the right to make changes and modifications to the design as necessary to the Intel RCFH-4 reference design, in particular the clip and fastener.



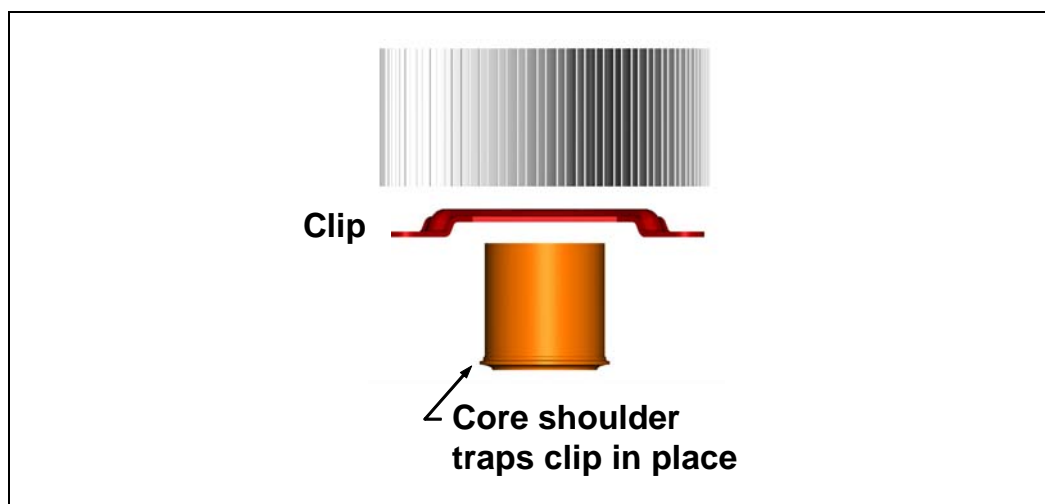
## 5.7.2 Mechanical Interface to the Reference Attach Mechanism

The attach mechanism component from the Intel RCFH-4 Reference Design can be used by other 3<sup>rd</sup> party cooling solutions. The attach mechanism consists of:

- A metal attach clip that interfaces with the heatsink core, see Appendix G, Figure 65 and Figure 66 for the component drawings.
- Four plastic fasteners, see Appendix G, Figure 67, Figure 68, Figure 69 and Figure 70 for the component drawings.

Figure 9 shows the reference attach mechanism as part of the Intel RCFH-4 Reference Design. The clip is assembled to the heatsink during copper core insertion, and is meant to be trapped between the core shoulder and the extrusion as shown in Figure 13. Figure 65 and Figure 66 in Appendix G provides additional details.

**Figure 13. Reference Clip/Heatsink Assembly**



The mechanical interface with the reference attach mechanism is defined in Figure 14 and Figure 15. Complying with the mechanical interface parameters is critical to generating a heatsink preload compliant with the minimum preload requirement given in Section 2.1.2.2.

Additional requirements for the reference attach mechanism (clip and fasteners) include:

- Total assembly mass, including heatsink/fan mass ( $\leq 550$  g), clip and fasteners  $< 595$  g
- Whole assembly center of gravity  $\leq 25.4$  mm, measured from the top of the IHS  
— Whole assembly = Heatsink + Fan + Attach clip + Fasteners.

Figure 14. Critical Parameters for Interfacing to Reference Clip

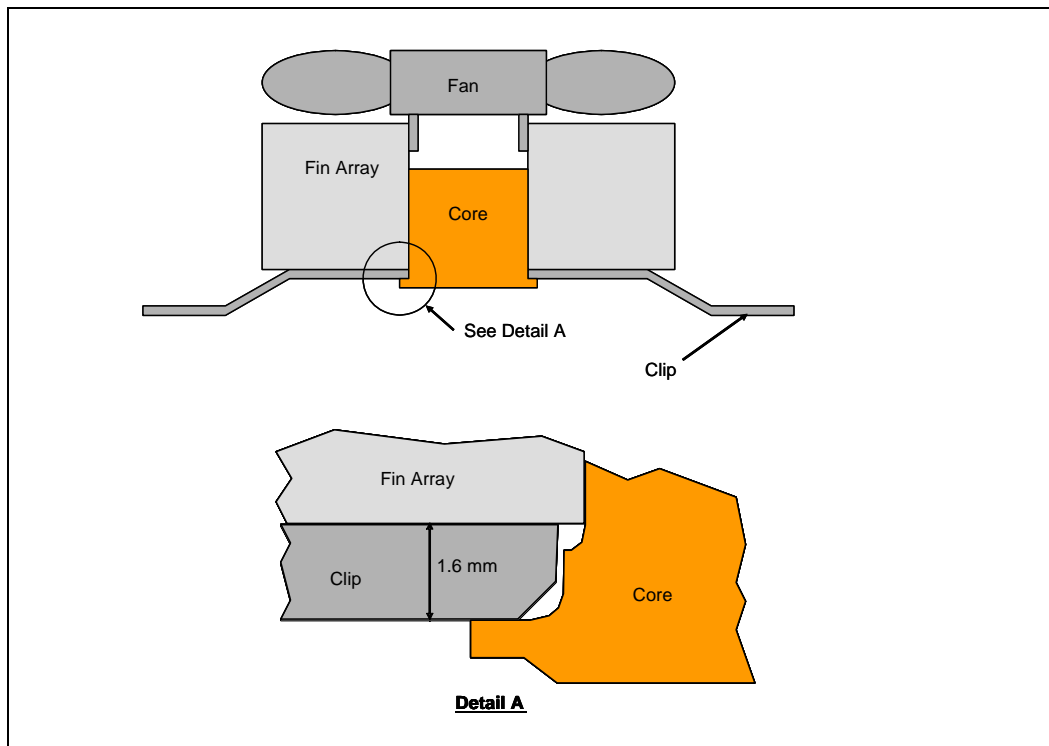
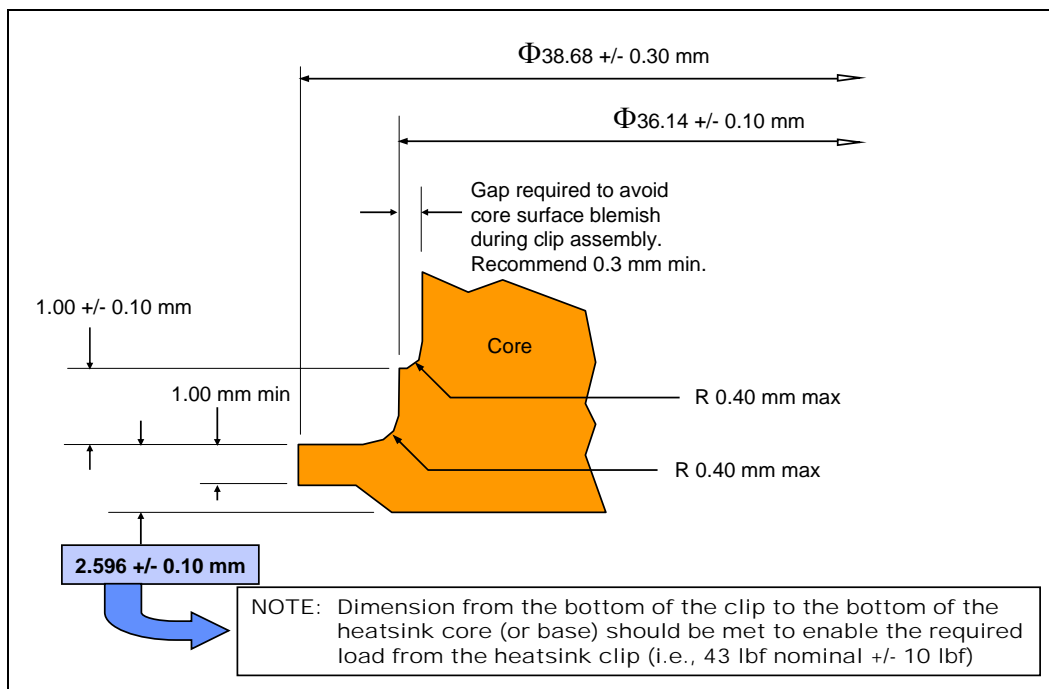


Figure 15. Critical Core Dimension





## 6 Acoustic Fan Speed Control

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### 6.1 Acoustic Fan Speed Control

As processor power has increased, the required thermal solutions have generated increasingly more noise. Intel has added an option to the processor thermal specifications that allows the system integrators to have a quieter system under typical usage.  $T_{\text{CONTROL}}$  and the on-die thermal diode provide the system integrator the means to implement a quieter system design.

Acoustic fan control implementations consist of the following items

- A motherboard designed with a fan speed controller with the following functionality:
  - PWM fan control output
  - Remote thermal diode measurement capability
- A motherboard with a 4 pin fan header for the processor heatsink fan.
- Processor heatsink with 4-wire PWM controlled Fan.  
A thermistor in the fan hub is recommended, but not a requirement. The reference solution and the Boxed Processor will implement a thermistor into the design.

The following sections discuss the necessary steps to implement Acoustic Fan Speed Control.

### 6.2 Thermal Solution Design

#### 6.2.1 Compliance to Thermal Profile

The first step is to select or design a processor thermal solution that meets the thermal profile for the processor. See Section 2.2.2 for the definition of the thermal profile and then consult the processor datasheet for the specific values.

The designer needs to ensure that when the heatsink fan is operating at full speed, the thermal solution will meet the  $T_{\text{C-MAX}}$  limits at TDP. The slope of the thermal profile allows the designer to make tradeoffs in thermal performance versus the inlet temperature to the processor fan heatsink.

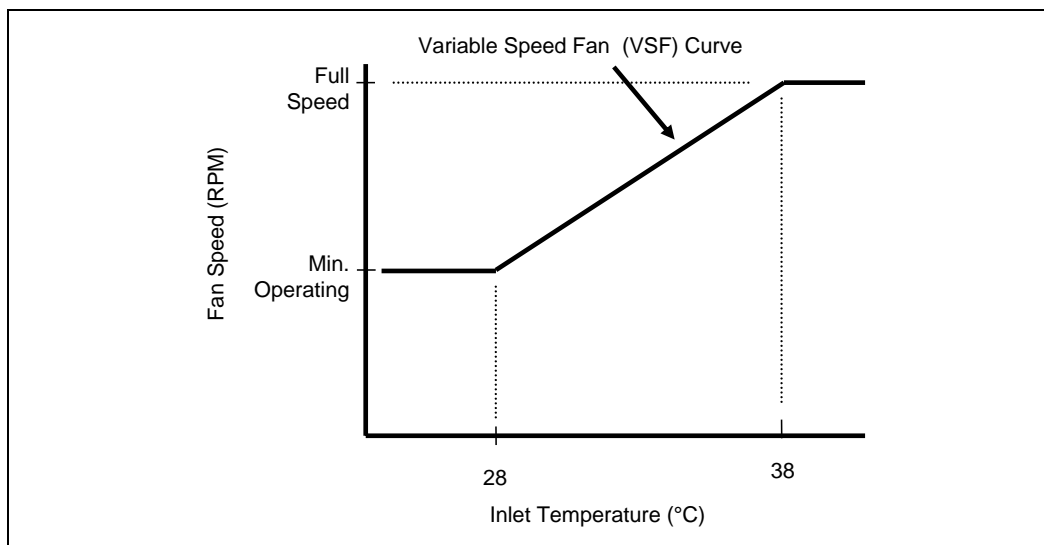
## 6.2.2 Determine Thermistor Set Points

A thermistor implemented in the hub of a fan is a first level of fan speed control. It provides an easy and cost effective means to begin acoustic noise reduction. It will, by design, run the fan at an appropriate speed based on the ambient conditions.

Chapter 5 discussed in detail the reference thermal solution, including the target  $\Psi_{CA}$ , fan speed based on temperature to ensure that  $T_{C-MAX}$  is not exceeded for TDP power at a given ambient temperature. The resulting variable speed fan (VSF) curve is the upper limit on fan speed.

The benefit of this upper limit will become more apparent when the fan speed controller is responding to the on-die thermal diode temperatures.

Figure 16. Thermistor Set Points



## 6.2.3 Minimum Fan Speed Set Point

The final aspect of thermal solution design is to determine the minimum speed at which the fan will be allowed to operate. This value can be driven by the cooling requirements for another portion of the design, such as the processor voltage regulator, or by functional limits of the fan design.

Per the *Fan Specification for 4 wire PWM Controlled Fans*; there are three possible options to consider:

- Type A: The fan will run at minimum RPM for all PWM duty cycle values less than minimum duty cycle. This would be programmed into the fan controller located on the fan hub. It can not be overridden by the external fan speed control.
- Type B: The fan will run at minimum RPM for all non-zero PWM duty cycle values less than minimum duty cycle and the fan will turn off at 0% PWM duty cycle.
- Type C: The fan will stop running when the current provided to the motor windings is insufficient to support commutation. The fan would turn off at 0% PWM duty cycle input.

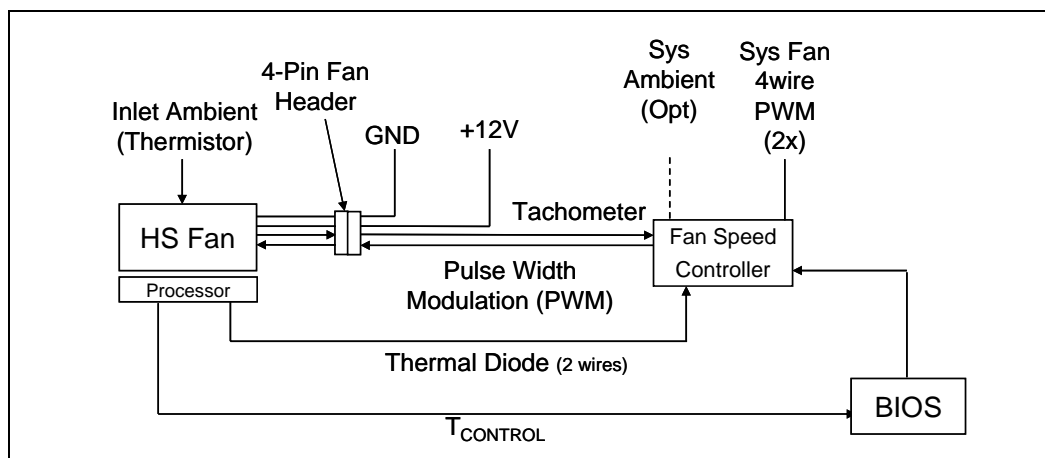
For the reference thermal solution, Type A was implemented.



## 6.3 Board and System Implementation

Once the thermal solution is defined, the system designer and board designer can define the fan speed control implementation. The first step is to select the appropriate fan speed controller (FSC). Figure 17 shows the major connections for a typical implementation.

Figure 17. Example Acoustic Fan Speed Control Implementation



A number of major manufacturers have FSC components that include the necessary functionality to measure the temperature of the on-die thermal diode and output a PWM signal. These components can be a discrete device or a super I/O (SIO) with the functionality embedded. The following vendors currently have components that could be suitable: Analog Devices, ITE, Maxim, National Semiconductor, SMSC and Winbond. Consult their web sites or local sales representatives for a part suitable for your design. See Appendix E for further details on the motherboard requirements.

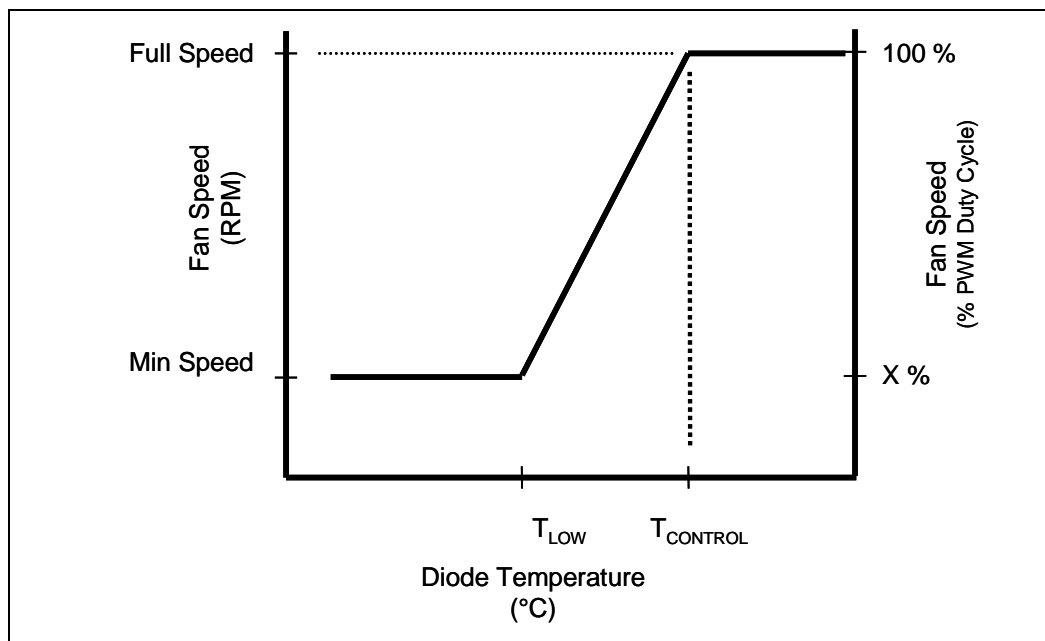
### 6.3.1 Choosing Fan Speed Control Settings

Fan speed control algorithms allow the system thermal engineer a number of options to consider. The typical control settings that need to be considered are:

- The temperature when the fan will begin to accelerate in response to the on-die thermal diode temperature ( $T_{LOW}$ ).
- The temperature where the fan speed is operating at full speed (100% PWM duty cycle). By specification this is  $T_{CONTROL}$ .
- For hardware monitor components that do not have a register that can be programmed for a fixed temperature error, the temperature where the fan is operating at full speed (100% PWM duty cycle) =  $T_{CONTROL} + \text{Thermal Diode Correction Factor}$ .
- The minimum fan speed (PWM duty cycle). For any on-die thermal diode temperature less than  $T_{LOW}$ , the fan will run at this speed.

These are the minimum parameters required to implement acoustic fan speed control. See Figure 18 for an example. There may be vendor specific options that offer enhanced functionality. See the appropriate vendor datasheet on how to implement those features.

Figure 18. Fan Speed Control



### 6.3.1.1 Temperature to begin fan acceleration

The first item to consider is the value for  $T_{LOW}$ . The FSC device needs a minimum temperature to set as the threshold to begin increasing PWM duty cycle to the fan.

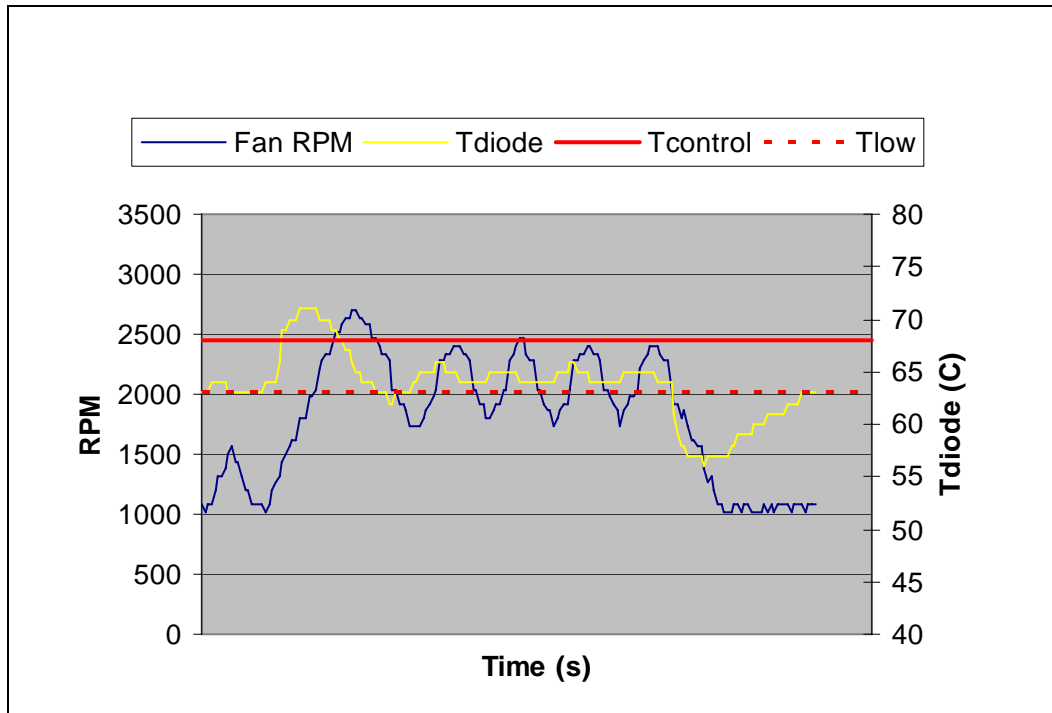
The system designer might initially consider a small temperature range ( $T_{CONTROL} - T_{LOW} = T_{RANGE}$ ), such as 5 °C to accelerate the fan. That would delay the fan accelerating for the longest period after an increase in  $T_{DIODE}$ . There are a number of issues that should be considered with this strategy:

- There is little granularity in the fan speeds. For each 1°C increase in diode temperature, there is a 20% jump in PWM duty cycle percent.
- Fan speed oscillation as the thermal solution chases the diode temperature.
- Having  $T_{DIODE}$  overshoot  $T_{CONTROL}$  and the thermal profile causing the Thermal Control Circuit to activate to reduce the temperature.
- In extreme cases THERMTRIP# activates and shuts down the processor.



The first two cases can create a poor acoustic response for the user. In the third case, the user could notice a drop in performance as the thermal control circuit reduces the power. Figure 19 is an example of this situation. The system begins at idle and a moderate workload is applied (less than TDP).

**Figure 19. Temperature Range = 5 °C**

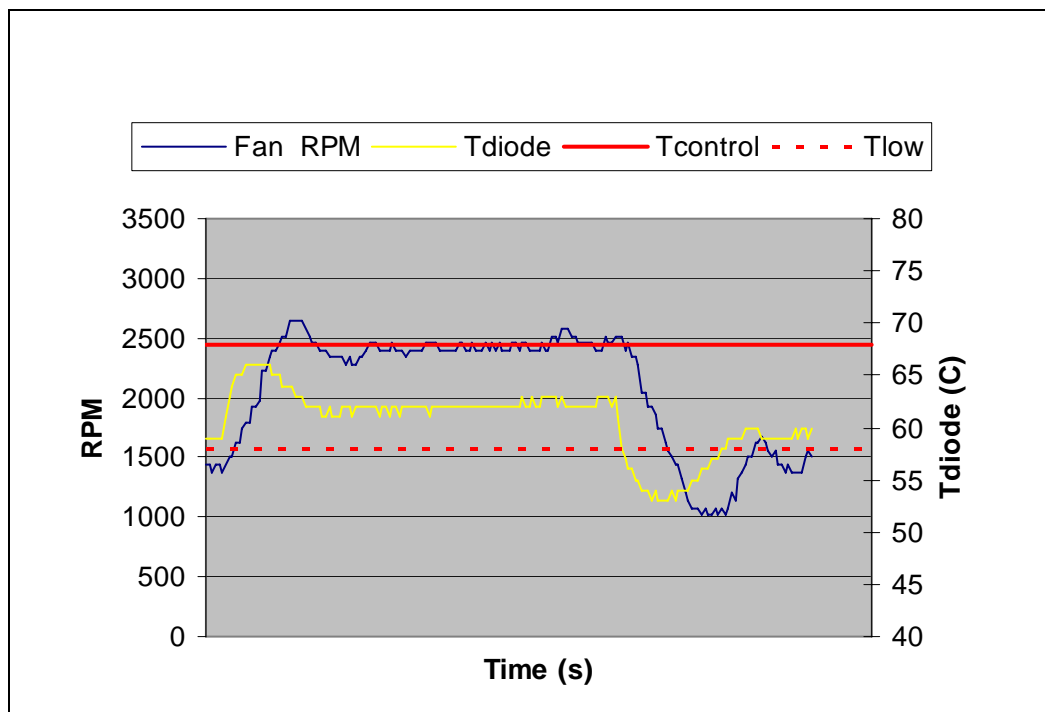


An alternate would be to consider a slightly larger value such as  $T_{\text{RANGE}} = 10\text{ }^{\circ}\text{C}$ . In this case the design is trading off the acoustic margin for thermal margin.

- There is increased granularity in the fan speeds.
- Fan speed oscillation is significantly reduced.
- Maximum fan speed is lower.

The rate of change of  $\Psi_{\text{CA}}$  vs. RPM is an exponential curve with a larger decrease at the beginning of the fan acceleration than as the maximum speed is approached. By having the fan start to accelerate at a lower  $T_{\text{DIODE}}$  reading the thermal solution can keep up with rate of change in processor power. The rate of change in acoustics (dBA) is more linear with RPM. When comparing these two metrics the choice of a larger  $T_{\text{RANGE}}$  value becomes a more acceptable trade off. Figure 20 graphs the system at the same conditions as in Figure 19, but  $T_{\text{RANGE}} = 10\text{ }^{\circ}\text{C}$ .

Figure 20. Temperature Range = 10 °C



It should be noted that having  $T_{DIODE}$  above  $T_{CONTROL}$  is expected for workloads near TDP power levels and high system ambient. See Section 6.5 for additional discussion on  $T_{CONTROL}$  versus Thermal Profile.

For use with the ATX Boxed Processor enabled reference solution, a  $T_{RANGE}$  value of 10 °C is recommended. For BTX Boxed Processor enabled reference solutions  $T_{RANGE}$  value of 7 °C is recommended.

**Note:** For hardware monitor components that do not have a register that can be programmed for a fixed temperature error then  $T_{LOW} = T_{CONTROL} - T_{RANGE} + \text{Thermal Diode Correction Factor}$ .

### 6.3.1.2 Minimum PWM Duty Cycle

The final step in determining the FSC setting is to determine the minimum PWM Duty cycle. This is the fan speed for any  $T_{DIODE} < T_{LOW}$ . The selection of this value is dependent on:

- Acoustic target at system idle
- Voltage regulator cooling

For a motherboard design intending to use the Boxed Processor or the enabled reference thermal solution, the recommended minimum PWM duty cycle is 20%.

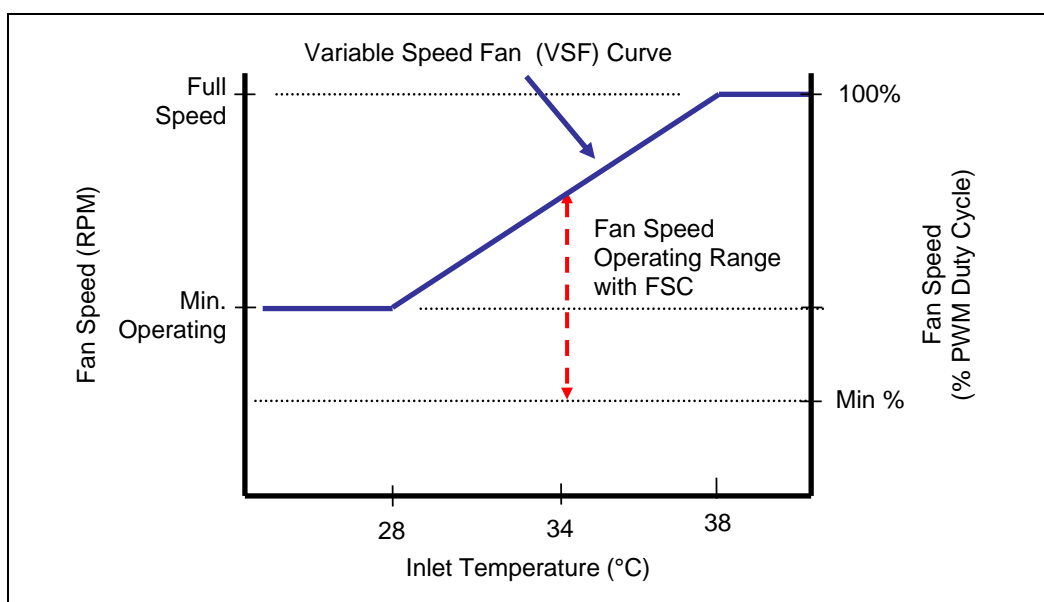
**Note:** Set minimum PWM Duty Cycle only as low as required to meet acoustic requirements. The FSC design needs to accommodate a transition from a low power state to TDP workloads without having PROCHOT# becoming active.



## 6.4 Combining Thermistor and Thermal Diode Control

There is no closed loop control between the FSC and the thermistor, but they work in tandem to provide the maximum fan speed reduction. As discussed in Section 6.2.2, the thermistor establishes the VSF curve. This curve will determine the maximum fan speed as a function of the ambient temperature and by design provides a  $\Psi_{CA}$  sufficient to meet the thermal profile. The FSC, by measuring the processor on-die thermal diode will command the fan to reduce speed below the VSF curve in response to processor workload. Conversely, if the processor workload increases, the FSC will command the fan via the PWM duty cycle to accelerate the fan up to the limit imposed by the VSF curve.

Figure 21. Diode and Thermistor



## 6.5 Interaction of Thermal Profile and $T_{\text{CONTROL}}$

The processor thermal specification is comprised of the two parameters,  $T_{\text{CONTROL}}$  and Thermal Profile. The minimum requirement for thermal compliance is to ensure the thermal solution, by design, meets the thermal profile.

If the system design will incorporate variable speed fan control, Intel requires monitoring the on-die thermal diode to implement acoustic fan speed control. The value of the on-die thermal diode temperature determines which specification must be met.

- On-die Thermal Diode less than  $T_{\text{CONTROL}}$ 
  - When the thermal solution can maintain the thermal diode temperature to less than  $T_{\text{CONTROL}}$ , then the fan speed can be reduced. .
- On-die Thermal Diode greater than  $T_{\text{CONTROL}}$ 
  - The  $T_c$  must be maintained at or below the Thermal Profile for the measured power dissipation.





# Appendix A LGA775 Socket Heatsink Loading

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## A.1 LGA775 Socket Heatsink Considerations

Heatsink clip load is traditionally used for:

- Mechanical performance in mechanical shock and vibration
  - Refer to Section 5.7.1 above for information on the structural design strategy for the Intel RCFH-4 Reference Design
- Thermal interface performance
  - Required preload depends on TIM
  - Preload can be low for thermal grease

In addition to mechanical performance in shock and vibration and TIM performance, LGA775 socket requires a minimum heatsink preload to protect against fatigue failure of socket solder joints.

Solder ball tensile stress is originally created when, after inserting a processor into the socket, the LGA775 socket load plate is actuated. In addition, solder joint shear stress is caused by coefficient of thermal expansion (CTE) mismatch induced shear loading. The solder joint compressive axial force ( $F_{axial}$ ) induced by the heatsink preload helps to reduce the combined joint tensile and shear stress.

Overall, the heatsink required preload is the minimum preload needed to meet all of the above requirements: Mechanical shock and vibration and TIM performance AND LGA775 socket protection against fatigue failure.

## A.2 Metric for Heatsink Preload for ATX/uATX Designs Non-Compliant with Intel<sup>®</sup> Reference Design

### A.2.1 Heatsink Preload Requirement Limitations

Heatsink preload by itself is not an appropriate metric for solder joint force across various mechanical designs and does not take into account for example (not an exhaustive list):

- Heatsink mounting hole span
- Heatsink clip/fastener assembly stiffness and creep
- Board stiffness and creep
- Board stiffness is modified by fixtures like backing plate, chassis attach, etc.



Simulation shows that the solder joint force ( $F_{\text{axial}}$ ) is proportional to the board deflection measured along the socket diagonal. The matching of  $F_{\text{axial}}$  required to protect the LGA775 socket solder joint in temperature cycling is equivalent to matching a target MB deflection.

Therefore, the heatsink preload for LGA775 socket solder joint protection against fatigue failure can be more generally defined as the load required to create a target board downward deflection throughout the life of the product.

This board deflection metric provides guidance for mechanical designs that differ from the reference design for ATX//μATX form factor.

## A.2.2 Motherboard Deflection Metric Definition

Motherboard deflection is measured along either diagonal (refer to Figure 22):

$$d = d_{\text{max}} - (d_1 + d_2)/2$$

$$d' = d_{\text{max}} - (d'_1 + d'_2)/2$$

Configurations in which the deflection is measured are defined in Table 7. To measure board deflection, follow industry standard procedures (such as IPC) for board deflection measurement. Height gauges and possibly dial gauges may also be used.

**Table 7. Board Deflection Configuration Definitions**

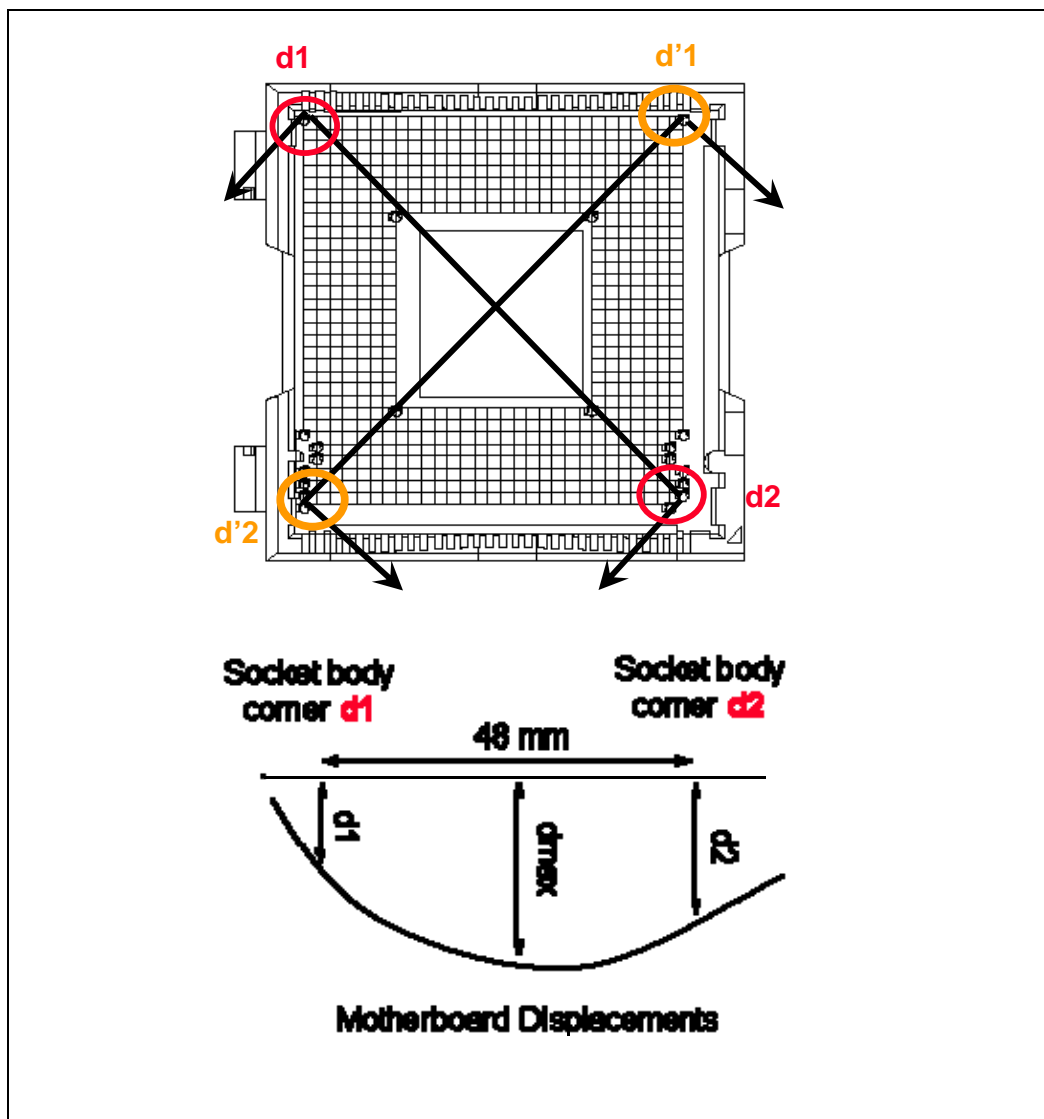
Configuration Parameter	Processor + Socket Load Plate	Heatsink	Parameter Name
d_ref	Yes	no	BOL deflection, no preload
d_BOL	Yes	yes	BOL deflection with preload
d_EOL	yes	yes	EOL deflection

**NOTES:**

1. BOL: Beginning of Life
2. EOL: End of Life



Figure 22. Board Deflection Definition



### A.2.3 Board Deflection Limits

Deflection limits for the ATX/μATX form factor are:

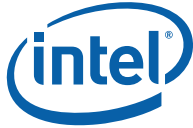
$$d_{\text{BOL}} - d_{\text{ref}} \geq 0.09 \text{ mm} \quad \text{and} \quad d_{\text{EOL}} - d_{\text{ref}} \geq 0.15 \text{ mm}$$

And

$$d'_{\text{BOL}} - d'_{\text{ref}} \geq 0.09 \text{ mm} \quad \text{and} \quad d'_{\text{EOL}} - d'_{\text{ref}} \geq 0.15 \text{ mm}$$

**NOTES:**

1. The heatsink preload must remain within the static load limits defined in the processor datasheet at all times.
2. Board deflection should not exceed motherboard manufacturer specifications.



## A.2.4 Board Deflection Metric Implementation Example

This section is for illustration purposes only, and relies on the following assumptions:

- 72 mm x 72 mm hole pattern of the reference design
- Board stiffness = 900 lb/in at BOL, with degradation that simulates board creep over time
  - Though these values are representative, they may change with selected material and board manufacturing process. Check with your motherboard vendor.
- Clip stiffness assumed constant – No creep.

Using Figure 23, the heatsink preload at beginning of life is defined to comply with  $d_{EOL} - d_{ref} = 0.15$  mm, depending on clip stiffness assumption.

Note that the BOL and EOL preload and board deflection differ. This is a result of the creep phenomenon. The example accounts for the creep expected to occur in the motherboard. It assumes no creep will occur in the clip. However, there is a small amount of creep accounted for in the plastic fasteners. This situation is somewhat similar to the Intel Reference Design.

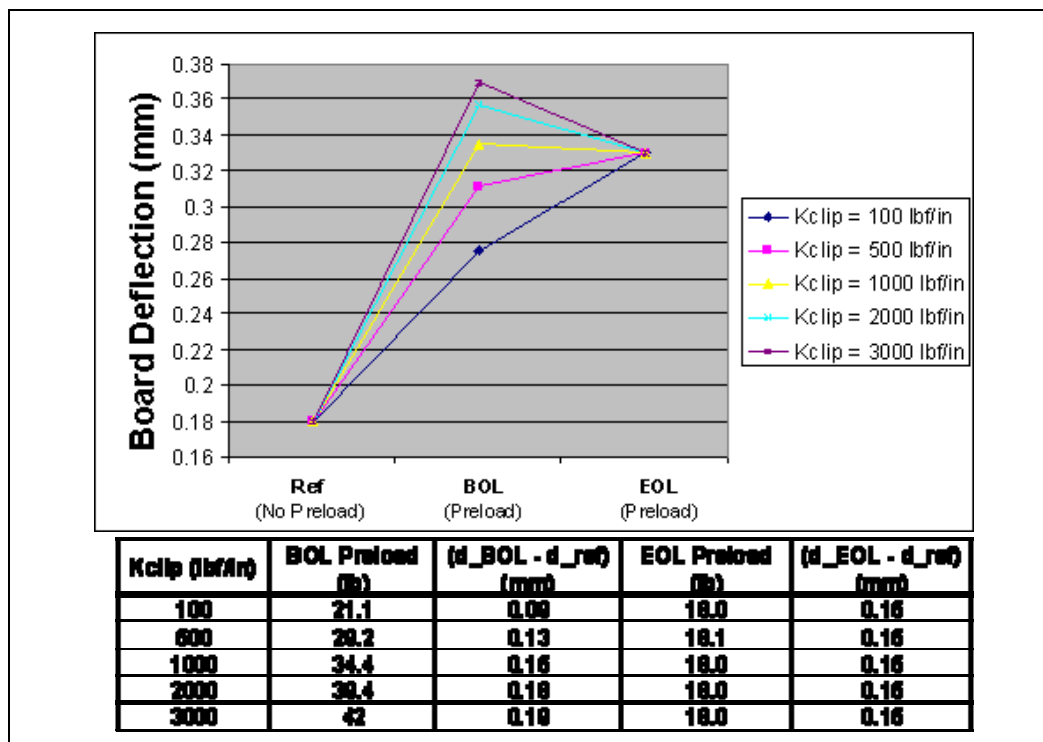
The impact of the creep to the board deflection is a function of the clip stiffness:

- The relatively compliant clips store strain energy in the clip under the BOL preload condition and tend to generate increasing amounts of board deflection as the motherboard creeps under exposure to time and temperature.
- In contrast, the stiffer clip stores very little strain energy, and therefore do not generate substantial additional board deflection through life.

### NOTES:

1. Board and clip creep modify board deflection over time and depend on board stiffness, clip stiffness, and selected materials.
2. Designers must define the BOL board deflection that will lead to the correct end of life board deflection

Figure 23. Example: Defining Heatsink Preload Meeting Board Deflection Limit



## A.2.5 Additional Considerations

Intel recommends designing to  $\{d_{BOL} - d_{ref} = 0.15 \text{ mm}\}$  at BOL when EOL conditions are not known or difficult to assess.

The following information is given for illustration only. It is based on the reference keep-out, assuming there is no fixture that changes board stiffness:

$d_{ref}$  is expected to be 0.18 mm on average, and be as high as 0.22 mm

As a result, the board should be able to deflect 0.37 mm minimum at BOL

Additional deflection as high as 0.09 mm may be necessary to account for additional creep effects impacting the board/clip/fastener assembly. As a result, designs could see as much as 0.50 mm total downward board deflection under the socket.

In addition to board deflection, other elements need to be considered to define the space needed for the downward board total displacement under load, like the potential interference of through-hole mount component pin tails of the board with a mechanical fixture on the back of the board.

### NOTES:

1. The heatsink preload must remain below the maximum load limit of the package at all times (Refer to processor datasheet).
2. Board deflection should not exceed motherboard manufacturer specifications.



### A.2.5.1 Motherboard Stiffening Considerations

To protect LGA775 socket solder joint, designers need to drive their mechanical design to:

- Allow downward board deflection to put the socket balls in a desirable force state to protect against fatigue failure of socket solder joint (refer to Sections A.2.1, A.2.2, and A.2.3).
- Prevent board upward bending during mechanical shock event.
- Define load paths that keep the dynamic load applied to the package within specifications published in the processor datasheet.

Limiting board deflection may be appropriate in some situations like:

- Board bending during shock.
- Board creep with high heatsink preload.

However, the load required to meet the board deflection recommendation (refer to Section A.2.3) with a very stiff board may lead to heatsink preloads exceeding package maximum load specification. For example, such a situation may occur when using a backing plate that is flush with the board in the socket area, and prevents the board from bending underneath the socket.

## A.3 Heatsink Selection Guidelines

Evaluate carefully heatsinks that use motherboard stiffening devices (like backing plates), and conduct board deflection assessments based on the board deflection metric.

Solutions derived from the reference design comply with the reference heatsink preload, for example:

- The Boxed Processor
- The Intel RCFH-4 reference design available from licensed suppliers (refer to Appendix H for contact information)

Intel will collaborate with vendors participating in its third party test house program to evaluate third party solutions. Vendor information will be available after product launch.



# Appendix B Heatsink Clip Load Metrology

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## B.1 Overview

This section describes a procedure for measuring the load applied by the heatsink/clip/fastener assembly on a processor package.

This procedure is recommended to verify the preload is within the design target range for a design, and in different situations. For example:

- Heatsink preload for the LGA775 socket
- Quantify preload degradation under bake conditions.

**Note:** This document reflects the current metrology used by Intel. Intel is continuously exploring new ways to improve metrology. Updates will be provided later as this document is revised as appropriate.

## B.2 Test Preparation

### B.2.1 Heatsink Preparation

Three load cells are assembled into the base of the heatsink under test, in the area interfacing with the processor Integrated Heat Spreader (IHS), using load cells equivalent to those listed in Section B.2.2.

To install the load cells, machine a pocket in the heatsink base, as shown Figure 24 and Figure 25. The load cells should be distributed evenly, as close as possible to the pocket walls. Apply wax around the circumference of each load cell and the surface of the pocket around each cell to maintain the load cells in place during the heatsink installation on the processor and motherboard (Refer to Figure 25).

The depth of the pocket depends on the height of the load cell used for the test. It is necessary that the load cells protrude out of the heatsink base. However, this protrusion should be kept minimal, as it will create additional load by artificially raising the heatsink base. The measurement offset depends on the whole assembly stiffness (i.e., motherboard, clip, fastener, etc.). For example, the Intel RCFH-4 Reference Heatsink Design clip and fasteners assembly stiffness was designed to be similar to the RCBFH-3 or around 380 N/mm [2180 lb/in]. In that case, a protrusion of 0.038 mm [0.0015"] will create an extra load of 15 N [3.3 lb]. Figure 26 shows an example using the Intel RCFH-4 Reference Heatsink.

**Note:** When optimizing the heatsink pocket depth, the variation of the load cell height should also be taken into account to make sure that all load cells protrude equally from the heatsink base. It may be useful to screen the load cells prior to installation to minimize variation.

### Remarks: Alternate Heatsink Sample Preparation

As mentioned above, making sure that the load cells have minimum protrusion out of the heatsink base is paramount to meaningful results. An alternate method to make sure that the test setup will measure loads representative of the non-modified design is:

- Machine the pocket in the heat sink base to a depth such that the tips of the load cells are just flush with the heat sink base.
- Then machine back the heatsink base by around 0.25 mm [0.01"], so that the load cell tips protrude beyond the base.

Proceeding this way, the original stack height of the heatsink assembly should be preserved. This should not affect the stiffness of the heatsink significantly.

**Figure 24. Load Cell Installation in Machined Heatsink Base Pocket (Bottom View)**

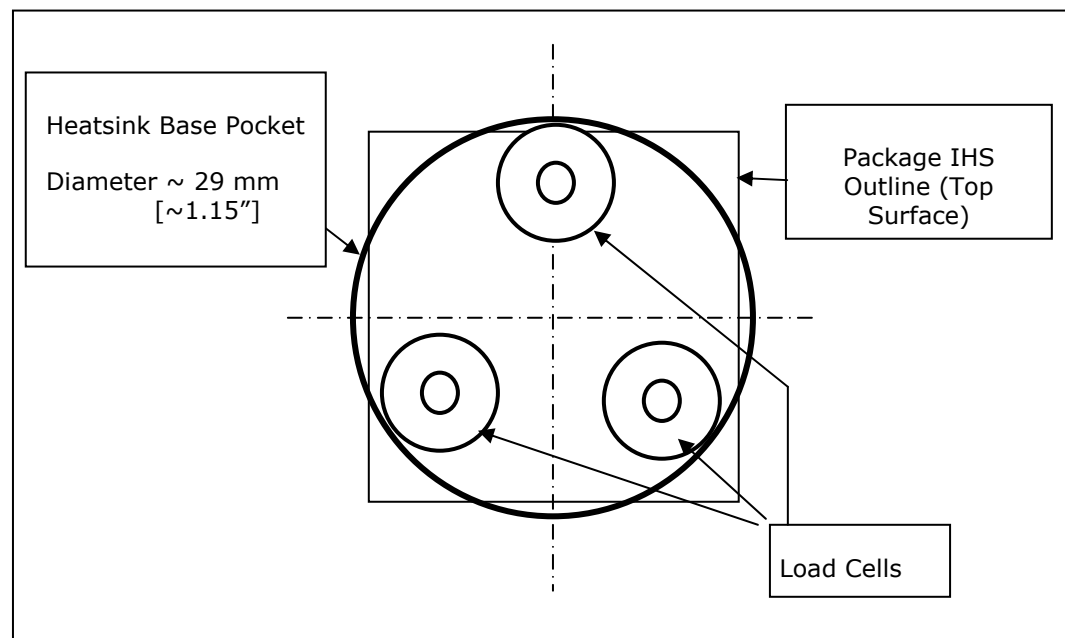




Figure 25. Load Cell Installation in Machined Heatsink Base Pocket (Side View)

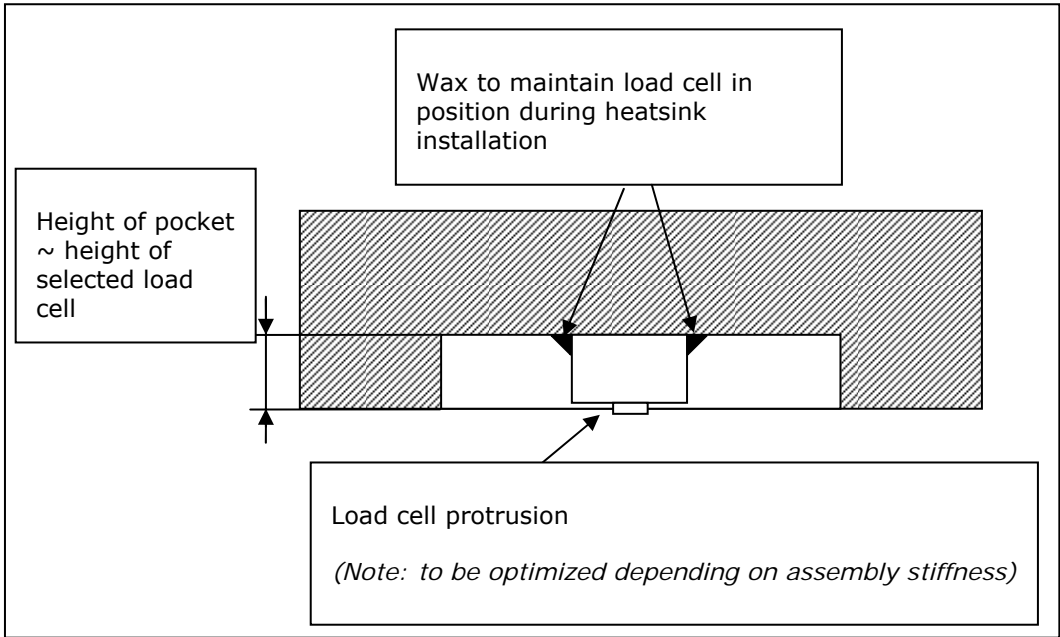
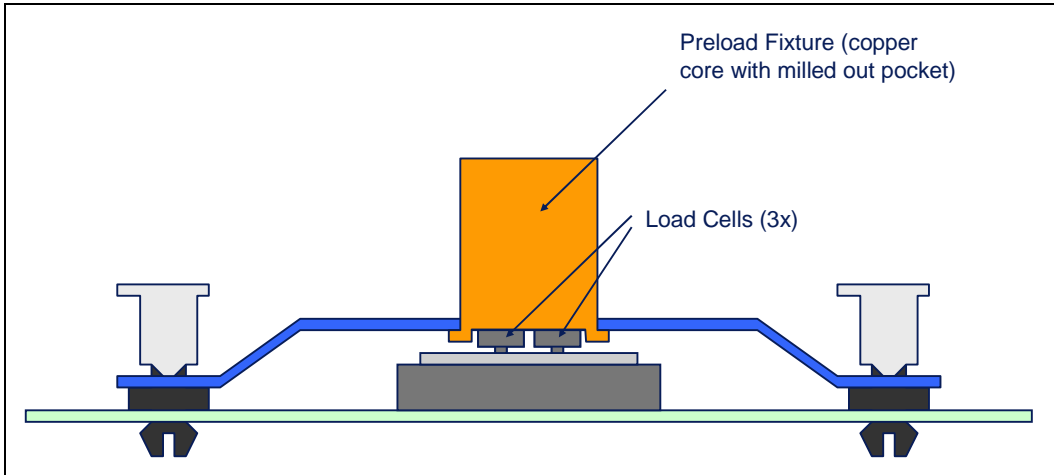


Figure 26. Preload Test Configuration





## B.2.2 Typical Test Equipment

For the heatsink clip load measurement, use equivalent test equipment to the one listed in Table 8.

Table 8. Typical Test Equipment

Item	Description	Part Number (Model)
Load cell <i>Notes: 1, 5</i>	Honeywell*-Sensotec* Model 13 subminiature load cells, compression only  Select a load range depending on load level being tested.  <a href="http://www.sensotec.com">www.sensotec.com</a>	AL322BL
Data Logger (or scanner) <i>Notes: 2, 3, 4</i>	Vishay* Measurements Group Model 6100 scanner with a 6010A strain card (one card required per channel).	Model 6100

**NOTES:**

1. Select load range depending on expected load level. It is usually better, whenever possible, to operate in the high end of the load cell capability. Check with your load cell vendor for further information.
2. Since the load cells are calibrated in terms of mV/V, a data logger or scanner is required to supply 5 volts DC excitation and read the mV response. An automated model will take the sensitivity calibration of the load cells and convert the mV output into pounds.
3. With the test equipment listed above, it is possible to automate data recording and control with a 6101-PCI card (GPIB) added to the scanner, allowing it to be connected to a PC running LabVIEW\* or Vishay's StrainSmart\* software.
4. **IMPORTANT:** In addition to just a zeroing of the force reading at no applied load, it is important to calibrate the load cells against known loads. Load cells tend to drift. Contact your load cell vendor for calibration tools and procedure information.
5. When measuring loads under thermal stress (bake for example), load cell thermal capability must be checked, and the test setup must integrate any hardware used along with the load cell. For example, the Model 13 load cells are temperature compensated up to 71 °C, as long as the compensation package (spliced into the load cell's wiring) is also placed in the temperature chamber. The load cells can handle up to 121 °C (operating), but their uncertainty increases according to 0.02% rdg/°F.





## B.3 Test Procedure Examples

The following sections give two examples of load measurement. However, this is not meant to be used in mechanical shock and vibration testing. Any mechanical device used along with the heatsink attach mechanism will need to be included in the test setup (i.e., back plate, attach to chassis, etc.). Prior to any test, make sure that the load cell has been calibrated against known loads, following load cell vendor's instructions.

### B.3.1 Time-Zero, Room Temperature Preload Measurement

1. Pre-assemble mechanical components on the board as needed prior to mounting the motherboard on an appropriate support fixture that replicate the board attach to a target chassis.
  - For example: standard ATX board should sit on ATX compliant stand-offs. If the attach mechanism includes fixtures on the back side of the board, those must be included, as the goal of the test is to measure the load provided by the actual heatsink mechanism.
2. Install test vehicle in the socket.
3. Assemble the heatsink reworked with the load cells to motherboard as shown for the Intel® RCFH-4 reference heatsink example in Figure 26, and actuate attach mechanism.
4. Collect continuous load cell data at 1 Hz for the duration of the test. A minimum time to allow the load cell to settle is generally specified by the load vendors (often in the order of 3 minutes). The time zero reading should be taken at the end of this settling time.
5. Record the preload measurement (total from all three load cells) at the target time and average the values over 10 seconds around this target time as well, i.e. in the interval , for example over [target time – 5 seconds ; target time + 5 seconds].

### B.3.2 Preload Degradation under Bake Conditions

This section describes an example of testing for potential clip load degradation under bake conditions.

1. Preheat thermal chamber to target temperature (45 °C or 85 °C for example)
2. Repeat time-zero, room temperature preload measurement
3. Place unit into preheated thermal chamber for specified time
4. Record continuous load cell data as follows:
  - Sample rate = 0.1 Hz for first 3 hrs
  - Sample rate = 0.01 Hz for the remainder of the bake test
5. Remove assembly from thermal chamber and set into room temperature conditions
6. Record continuous load cell data for next 30 minutes at sample rate of 1 Hz.

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## Appendix C Thermal Interface Management

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To optimize a heatsink design, it is important to understand the impact of factors related to the interface between the processor and the heatsink base. Specifically, the bond line thickness, interface material area and interface material thermal conductivity should be managed to realize the most effective thermal solution.

### C.1 Bond Line Management

Any gap between the processor integrated heat spreader (IHS) and the heatsink base degrades thermal solution performance. The larger the gap between the two surfaces, the greater the thermal resistance. The thickness of the gap is determined by the flatness and roughness of both the heatsink base and the integrated heat spreader, plus the thickness of the thermal interface material (for example, thermal grease) used between these two surfaces and the clamping force applied by the heatsink attach clip(s).

### C.2 Interface Material Area

The size of the contact area between the processor and the heatsink base will impact the thermal resistance. There is, however, a point of diminishing returns. Unrestrained incremental increases in thermal interface material area do not translate to a measurable improvement in thermal performance.

### C.3 Interface Material Performance

Two factors impact the performance of the interface material between the processor and the heatsink base:

- Thermal resistance of the material
- Wetting/filling characteristics of the material

Thermal resistance is a description of the ability of the thermal interface material to transfer heat from one surface to another. The higher the thermal resistance, the less efficient the interface material is at transferring heat. The thermal resistance of the interface material has a significant impact on the thermal performance of the overall thermal solution. The higher the thermal resistance, the larger the temperature drop is across the interface and the more efficient the thermal solution (heatsink, fan) must be to achieve the desired cooling.

The wetting or filling characteristic of the thermal interface material is its ability, under the load applied by the heatsink retention mechanism, to spread and fill the gap between the processor and the heatsink. Since air is an extremely poor thermal conductor, the more completely the interface material fills the gaps, the lower the temperature drops across the interface. In this case, thermal interface material area also becomes significant; the larger the desired thermal interface material area, the higher the force required to spread the thermal interface material.





## Appendix D Case Temperature Reference Metrology

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### D.1 Objective and Scope

This appendix defines a reference procedure for attaching a thermocouple to the IHS of a 775-land LGA package for  $T_C$  measurement. This procedure takes into account the specific features of the 775-land LGA package and of the LGA775 socket for which it is intended. The recommended equipment for the reference thermocouple installation, including tools and part numbers are also provided.

**Note:** This procedure is not applicable to the Intel® Pentium® 4 processors. See the *Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal and Mechanical Design Guidelines* available at <http://www.intel.com/design/Pentium4/guides/302553.htm> for the appropriate thermocouple attach procedure.



## D.2 Supporting Test Equipment

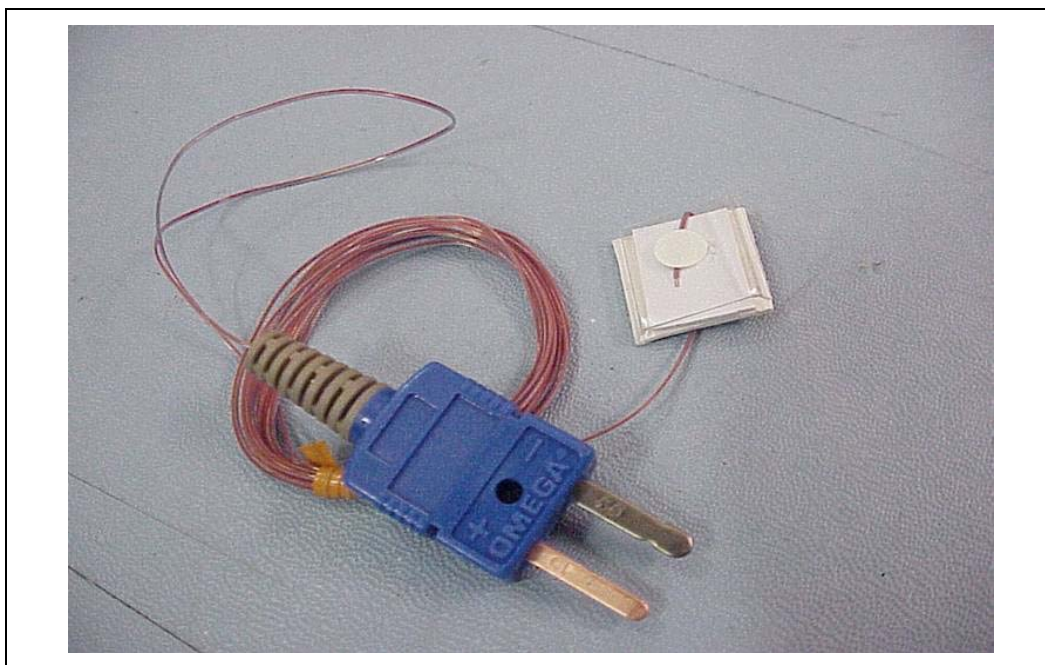
To apply the reference thermocouple attach procedure, it is recommended to use the equipment (or equivalent) given in the following table.

Item	Description	Part Number
Measurement and Output		
Microscope	Olympus* Light microscope or equivalent	SZ-40
DMM	Digital Multi Meter for resistance measurement	Fluke 79 Series
Thermal Meter	Hand held thermocouple meter	Multiple Vendors
Solder Station (see note 1 for ordering information)		
Heater Block	Heater assembly to reflow solder on IHS	30330
Heater	WATLOW120V 150W Firerod	0212G G1A38-L12
Transformer	Superior Powerstat transformer	05F857
Miscellaneous Hardware		
Solder	Indium Corp. of America Alloy 57BI / 42SN / 1AG 0.010 Diameter	52124
Flux	Indium Corp. of America	5RMA
Loctite* 498 Adhesive	Super glue w/thermal characteristics	49850
Adhesive Accelerator	Loctite* 7452 for fast glue curing	18490
Kapton* Tape	For holding thermocouple in place	Not Available
Thermocouple	Omega *,36 gauge, "T" Type (see note 2 for ordering information)	OSK2K1280/5SR TC-TT-T-36-72
Calibration and Control		
Ice Point Cell	Omega*, stable 0 °C temperature source for calibration and offset	TRCIII
Hot Point Cell	Omega *, temperature source to control and understand meter slope gain	CL950-A-110

### NOTES:

1. The Solder Station consisting of the Heater Block, Heater, Press and Transformer are available from Jemelco Engineering 480-804-9514
2. This part number is a custom part with the specified insulation trimming and packaging requirements necessary for quality thermocouple attachment, See Figure 27. Order from Omega Anthony Alvarez, Direct phone (203) 359-7671, Direct fax (203) 968-7142, E-Mail: aalvarez@omega.com

Figure 27. Omega Thermocouple



## D.3 Thermal Calibration and Controls

It is recommended that full and routine calibration of temperature measurement equipment be performed before attempting to perform temperature case measurement of any device. Intel recommends checking the meter probe set against known standards. This should be done at 0 °C (using ice bath or other stable temperature source) and at an elevated temperature, around 80 °C (using an appropriate temperature source).

Wire gauge and length also should be considered as some less expensive measurement systems are heavily impacted by impedance. There are numerous resources available throughout the industry to assist with implementation of proper controls for thermal measurements.

**Note:**

1. It is recommended to follow standard safety procedures and wear safety items like glasses for cutting the IHS and gloves for chemical handling.
2. Ask your Intel field sales representative if you would like assistance to groove and/or install a thermocouple according to the reference process.

## D.4 IHS Groove

Cut a groove in the package IHS according to the drawing given in Figure 28.

Figure 28. 775-LAND LGA Package Reference Groove Drawing

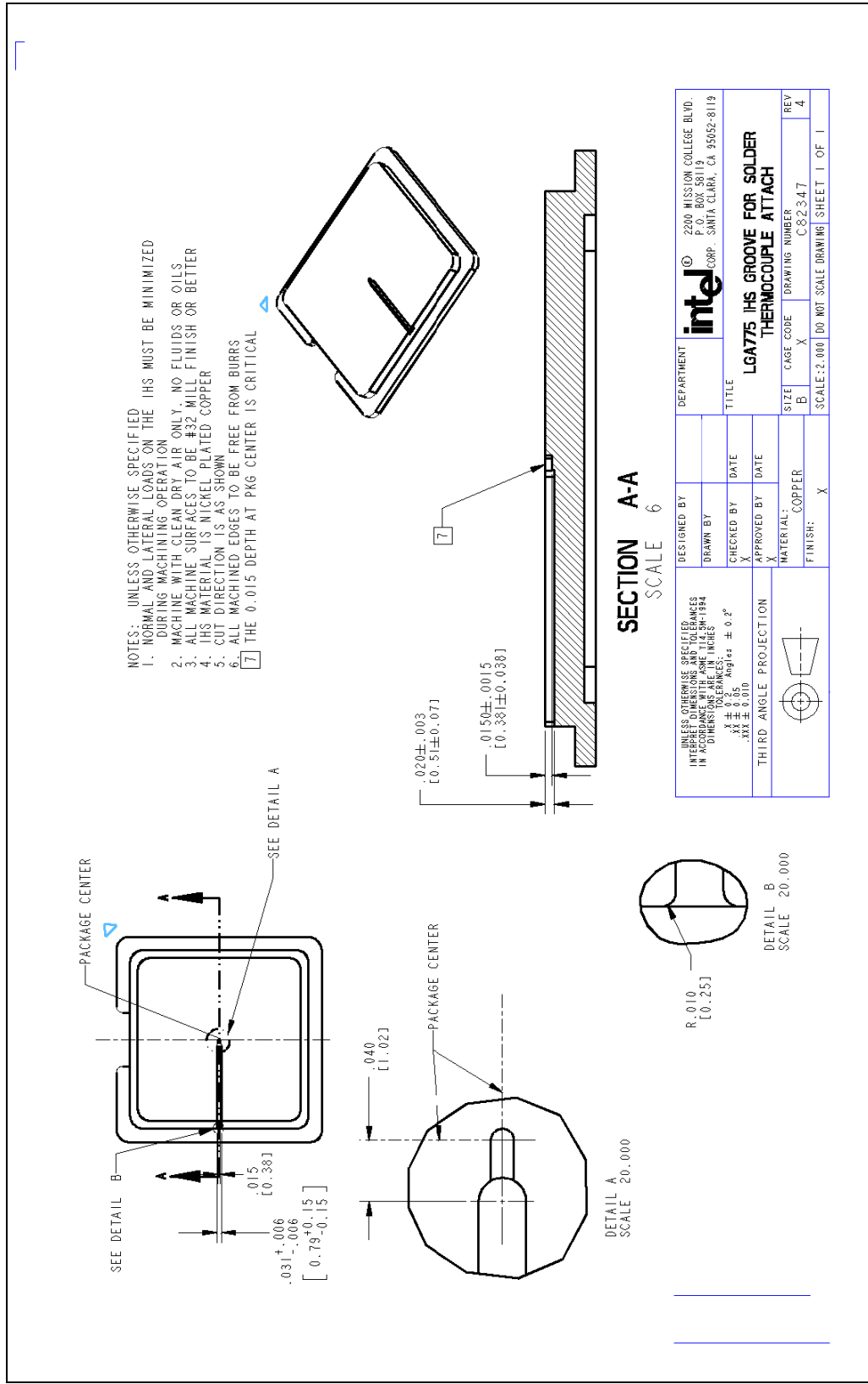
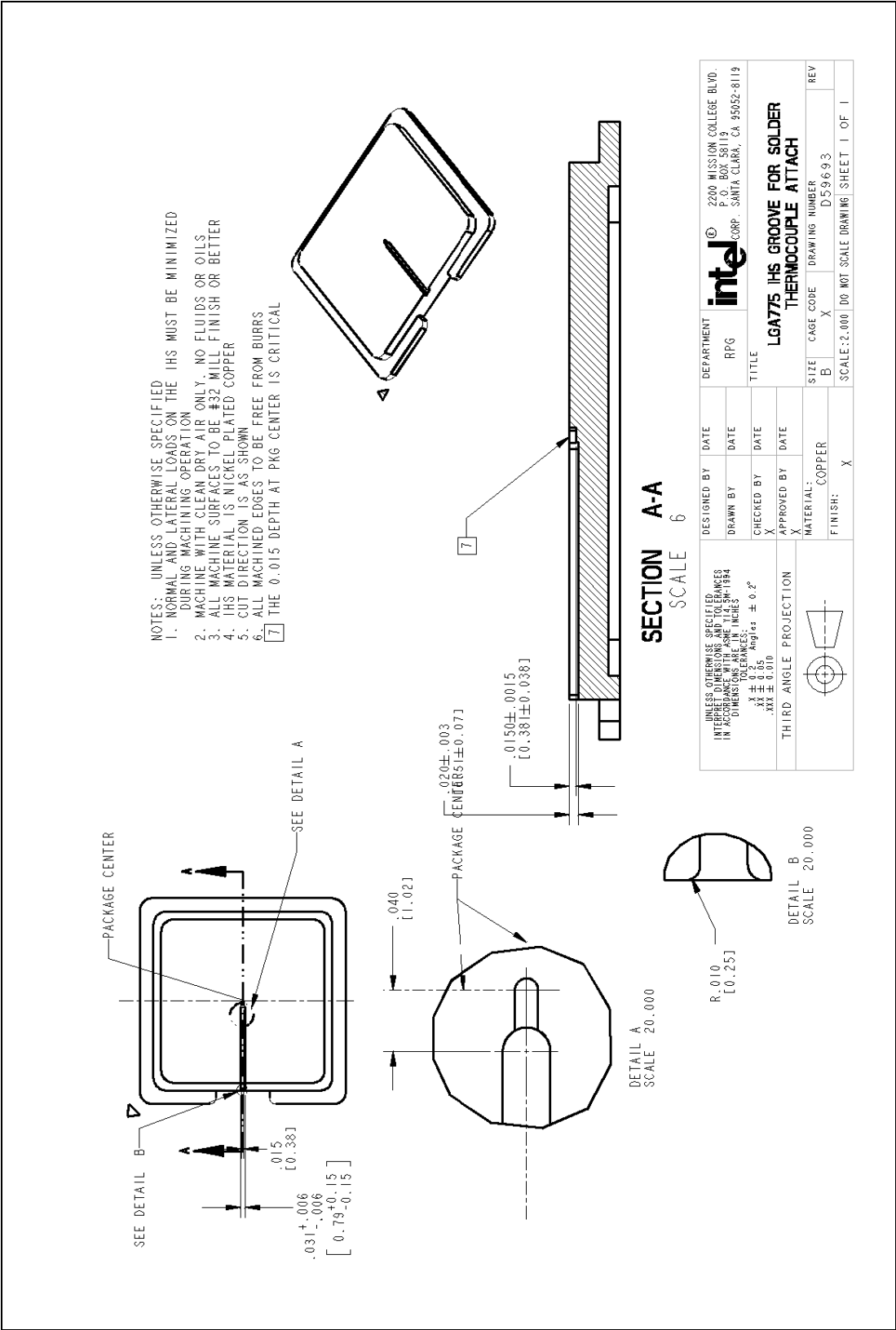




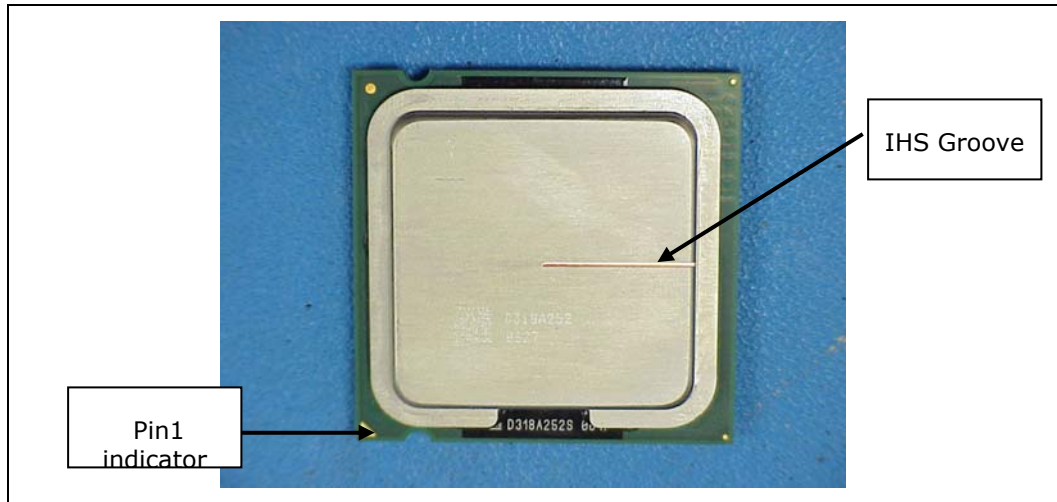


Figure 29. 775-LAND LGA Package Reference Groove Drawing Alternate Orientation



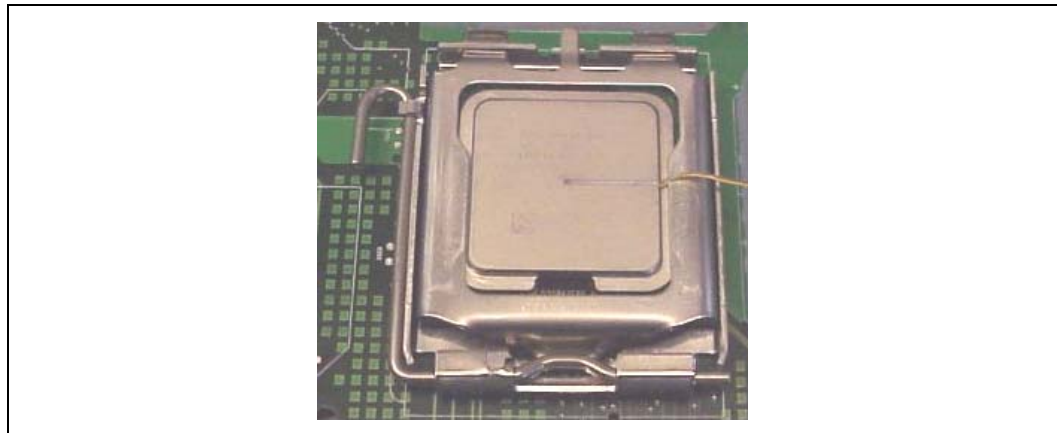
The orientation of the groove relative to the package pin 1 indicator (gold triangle in one corner of the package) is shown. Figure 30 for the 775-Land LGA package IHS.

**Figure 30. IHS Groove on the 775-LAND LGA Package**



When the processor is installed in the LGA775 socket, the groove is perpendicular to the socket load lever, and on the opposite side of the lever, as shown in Figure 31.

**Figure 31. IHS Groove Orientation Relative to the LGA775 Socket**



Select a machine shop that is capable of complying with drawing specified tolerances. IHS groove geometry is critical for repeatable placement of the thermocouple bead, ensuring precise thermal measurements. The specified dimensions minimize the impact of the groove on the IHS under the socket load. A larger groove may cause the IHS to warp under the socket load such that it does not represent the performance of an ungrooved IHS on production packages.

Inspect parts for compliance to specifications before accepting from machine shop.

## D.5 Thermocouple Attach Procedure

The procedure to attach a thermocouple with solder takes about 15 minutes to complete. Before proceeding turn on the solder block heater, as it can take up to 30 minutes to reach the target temperature of 153 – 155 °C.

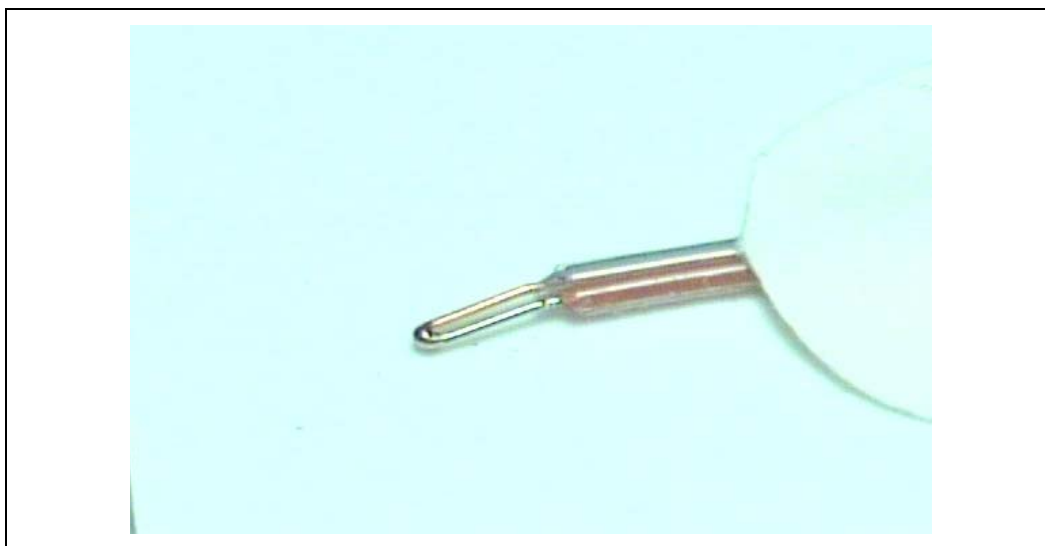
**Note:** To avoid damage to the processor ensure the IHS temperature does not exceed 155 °C.

As a complement to the written procedure a video *Thermocouple Attach Using Solder* – Video CD-ROM is available.

### D.5.1 Thermocouple Conditioning and Preparation

1. Use a calibrated thermocouple as specified in Sections D.2 and D.3.
2. Under a microscope, verify the thermocouple insulation meets the quality requirements. The insulation should be about 1/16 inch ( $0.062 \pm 0.030$ ) from the end of the bead (Figure 32).

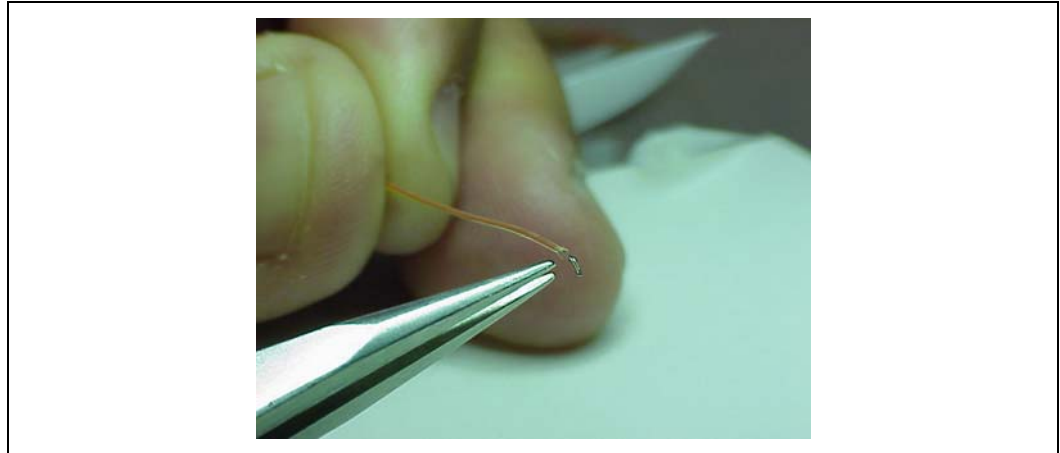
Figure 32. Inspection of Insulation on Thermocouple



3. Measure the thermocouple resistance by holding both contacts on the connector on one probe and the tip of thermocouple to the other probe of the DMM (measurement should be about  $\sim 3.0 \Omega$  for 36-gauge type T thermocouple).
4. Straighten the wire for about 38 mm [1 ½ inch] from the bead.

5. Using the microscope and tweezers, bend the tip of the thermocouple at approximately 10 degree angle by about 0.8 mm [.030 inch] from the tip (Figure 33).

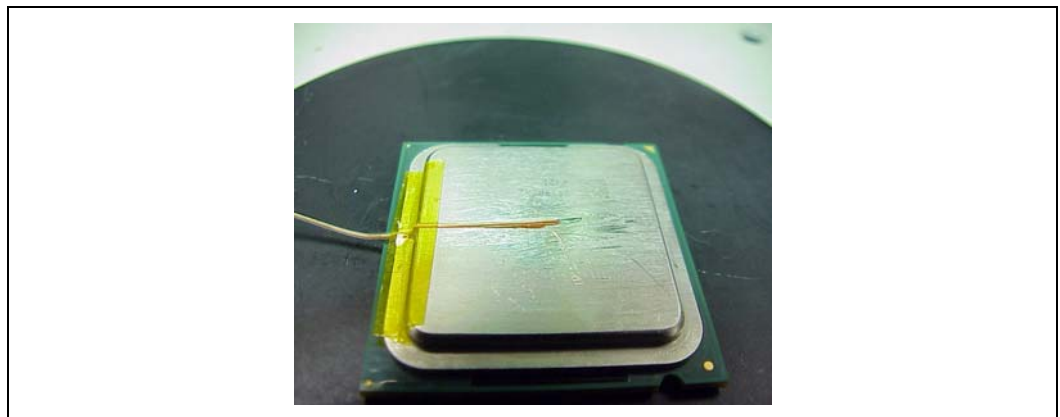
**Figure 33. Bending the Tip of the Thermocouple**



## D.5.2 Thermocouple Attachment to the IHS

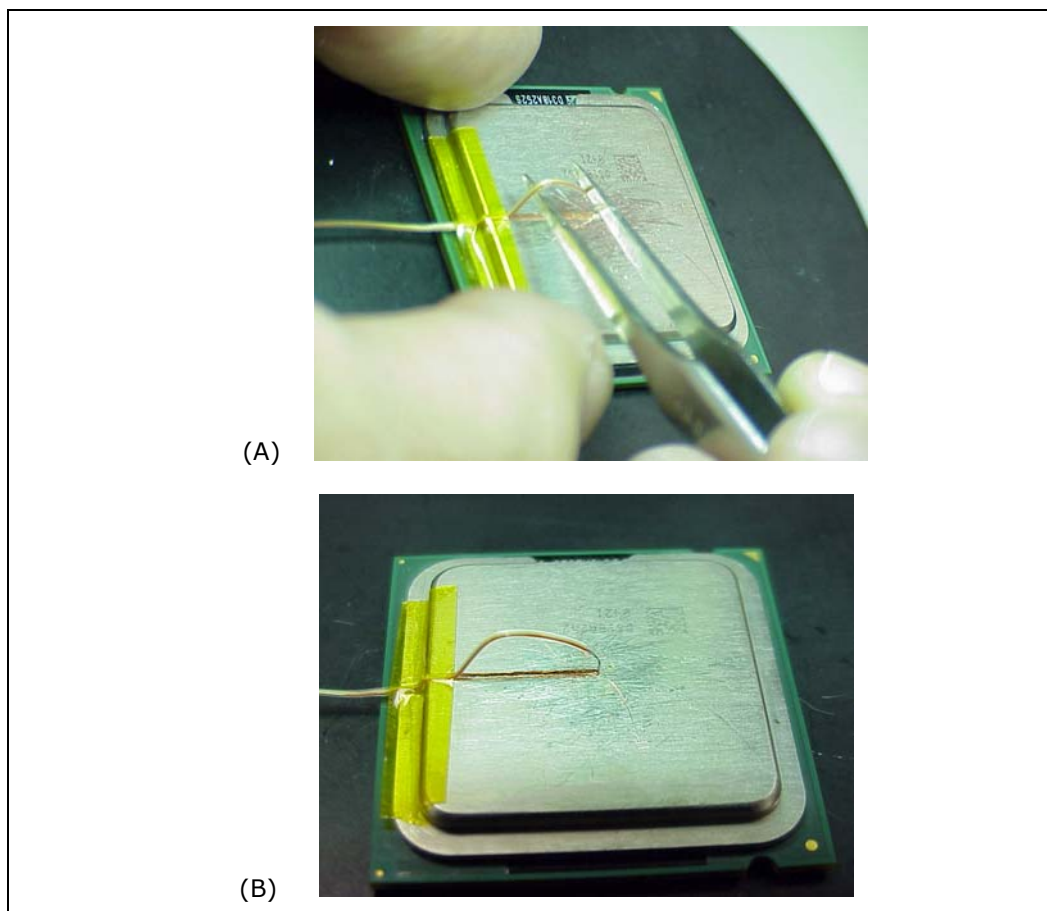
6. Clean groove and IHS with Isopropyl Alcohol (IPA) and a lint free cloth removing all residues prior to thermocouple attachment.
7. Place the thermocouple wire inside the groove; letting the exposed wire and bead extend about 1.5 mm [0.030 inch] past the end of groove. Secure it with Kapton\* tape (Figure 34). Clean the IHS with a swab and IPA.
8. Verify under the microscope that the thermocouple wires are straight and parallel in the groove and that the bead is still bent.

**Figure 34. Securing Thermocouple Wires with Kapton\* Tape Prior to Attach**



9. Lift the wire at the middle of groove with tweezers and bend the front of wire to place the thermocouple in the groove ensuring the tip is in contact with the end and bottom of the groove in the IHS (Figure 35-A and B).

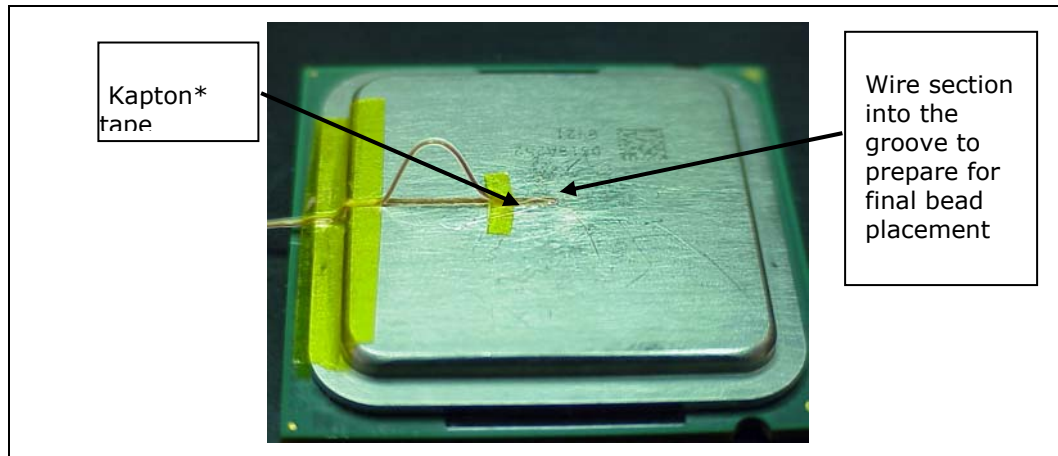
**Figure 35. Thermocouple Bead Placement**



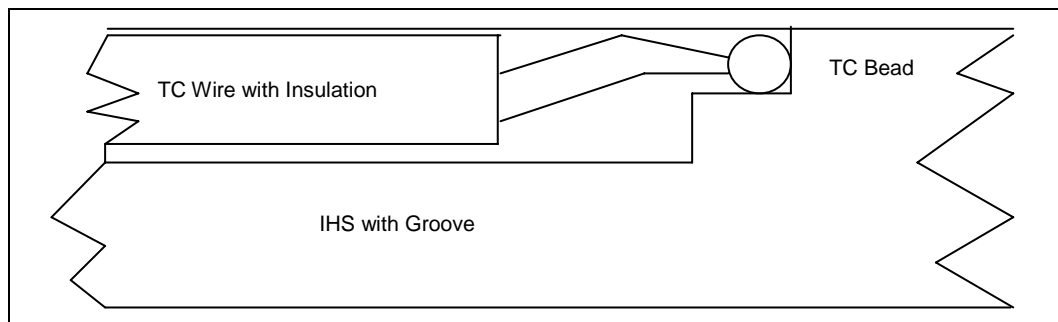
10. Place the package under the microscope to continue with process. It is also recommended to use a fixture (like processor tray or a plate) to help holding the unit in place for the rest of the attach process.

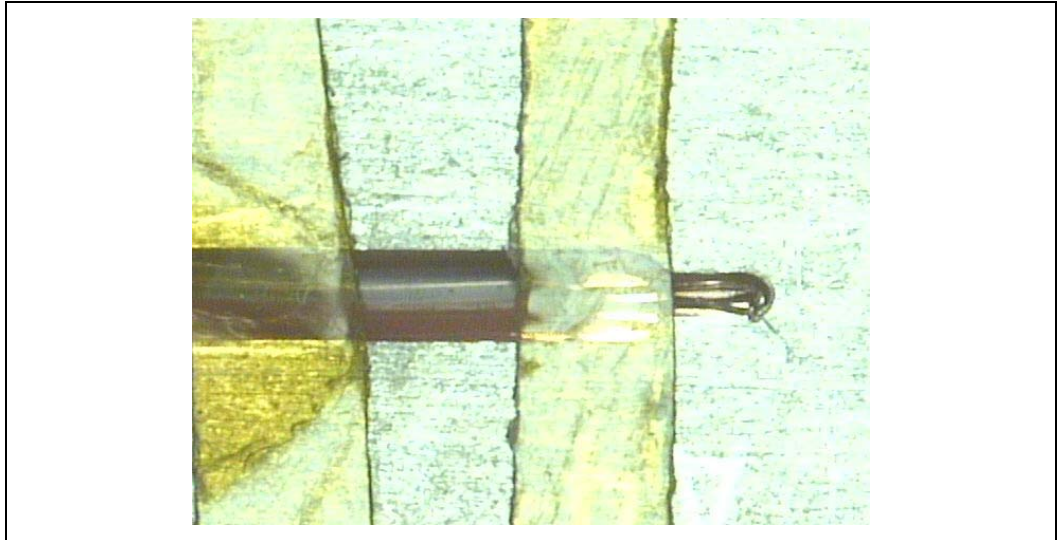
11. While still at the microscope, press the wire down about 6mm [0.125"] from the thermocouple bead using the tweezers or your finger. Place a piece of Kapton\* tape to hold the wire inside the groove (Figure 36). Refer to Figure 37 for detailed bead placement.

**Figure 36. Position Bead on the Groove Step**

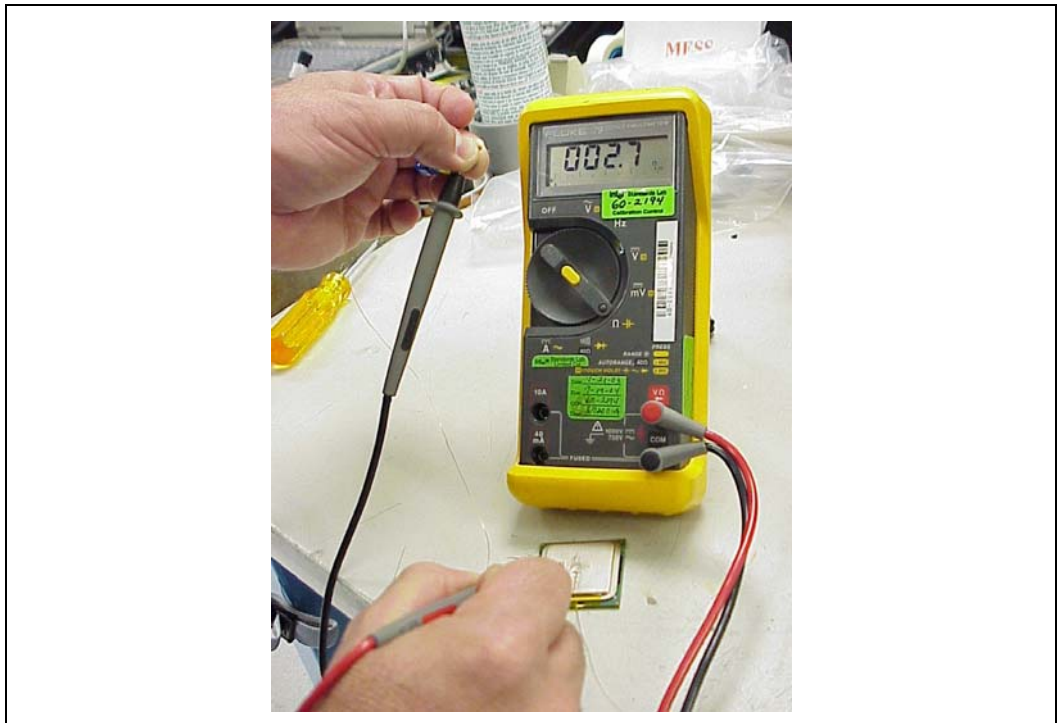


**Figure 37. Detailed Thermocouple Bead Placement**



**Figure 38. Third Tape Installation**

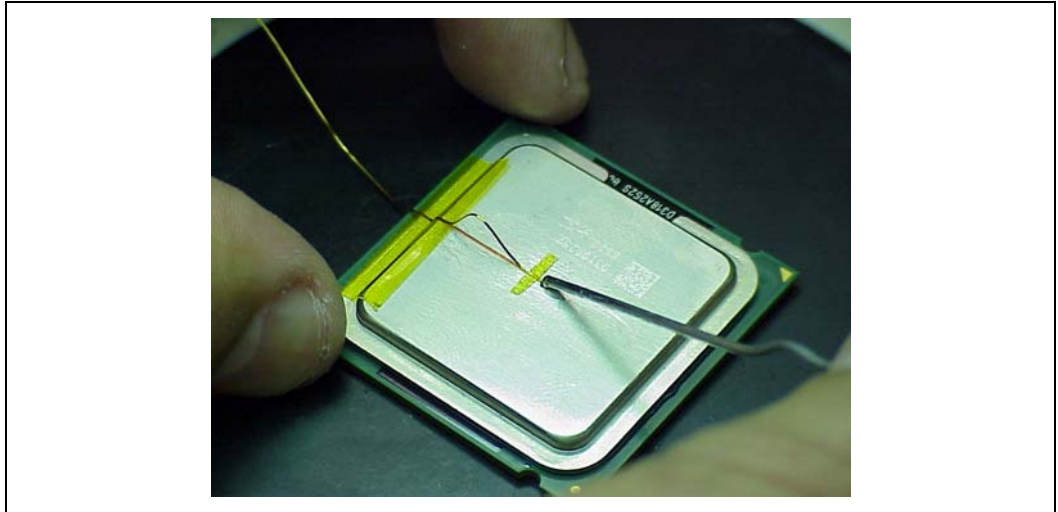
12. Place a 3<sup>rd</sup> piece of tape at the end of the step in the groove as shown in Figure 38. This tape will create a solder dam to prevent solder from flowing into the larger IHS groove section during the melting process.
13. Measure resistance from thermocouple end wires (hold both wires to a DMM probe) to the IHS surface. This should be the same value as measured during the thermocouple conditioning step D.5.1, step 3 (Figure 39).

**Figure 39. Measuring Resistance between Thermocouple and IHS**



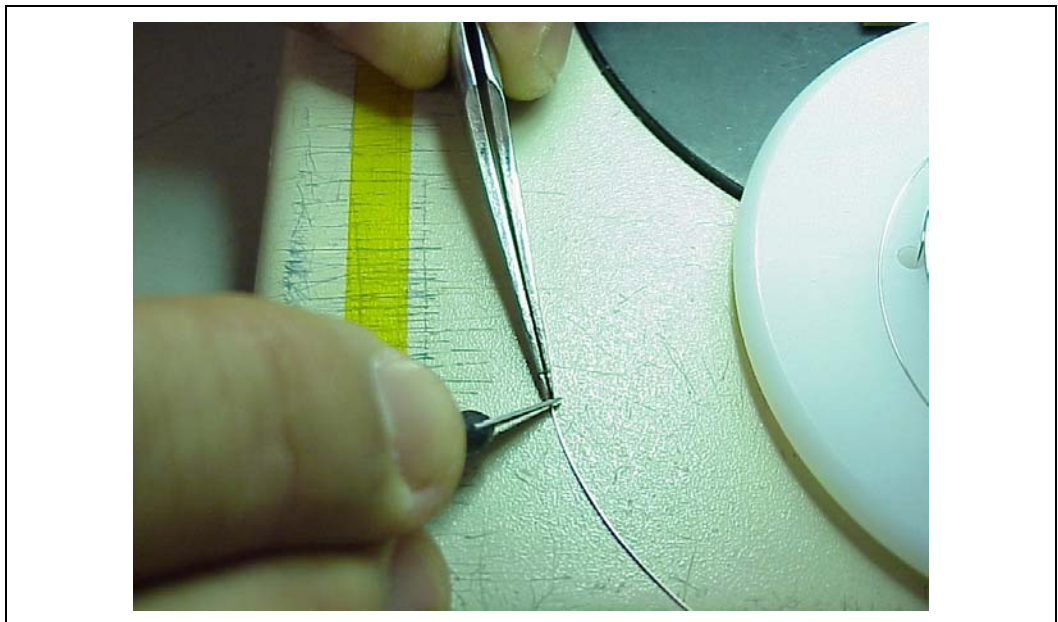
14. Using a fine point device, place a small amount of flux on the thermocouple bead. Be careful not to move the thermocouple bead during this step (Figure 40). Ensure the flux remains in the bead area only.

**Figure 40. Applying Flux to the Thermocouple Bead**



15. Cut two small pieces of solder 1/16 inch (0.065 inch / 1.5 mm) from the roll using tweezers to hold the solder while cutting with a fine blade (Figure 41).

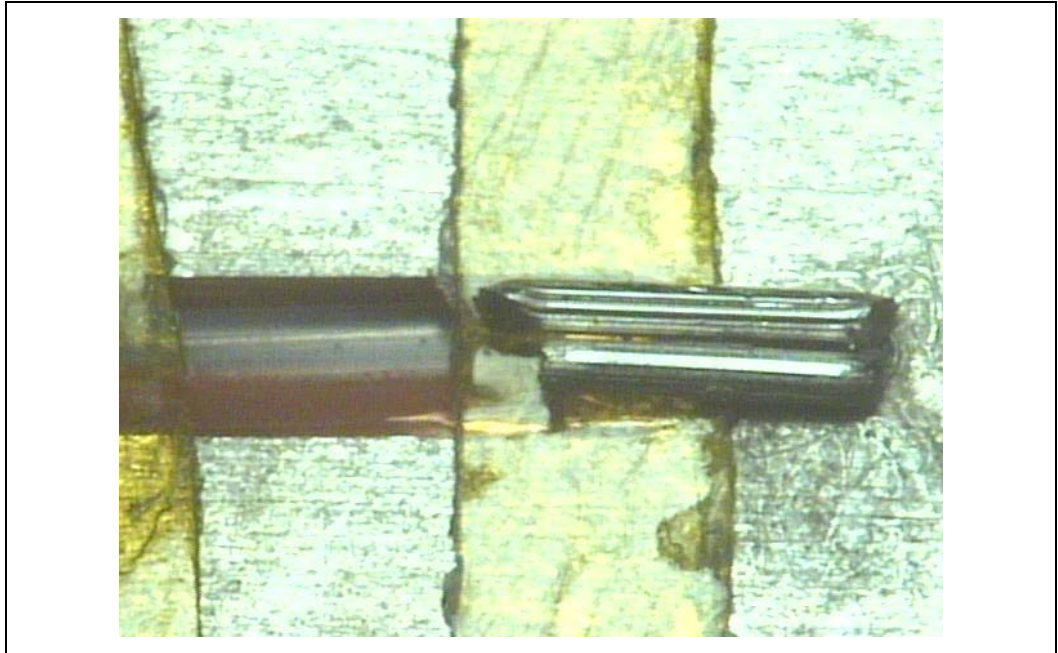
**Figure 41. Cutting Solder**





16. Place the two pieces of solder in parallel, directly over the thermocouple bead (Figure 42).

**Figure 42. Positioning Solder on IHS**



17. Measure the resistance from the thermocouple end wires again using the DMM (refer to Section D.5.1, step 2) to ensure the bead is still properly contacting the IHS.

### **D.5.3 Solder Process**

18. Make sure the thermocouple that monitors the Solder Block temperature is positioned on the Heater block. Connect the thermocouple to a handheld meter to monitor the heater block temperature
19. Verify the temperature of the Heater block station has reached  $155\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$  before you proceed.

20. Connect the thermocouple for the device being soldered to a second hand held meter to monitor IHS temperature during the solder process.

**Figure 43. Solder Station Setup**



21. Remove the land side protective cover and place the device to be soldered in the solder station. Make sure the thermocouple wire for the device being soldered is exiting the heater toward you.

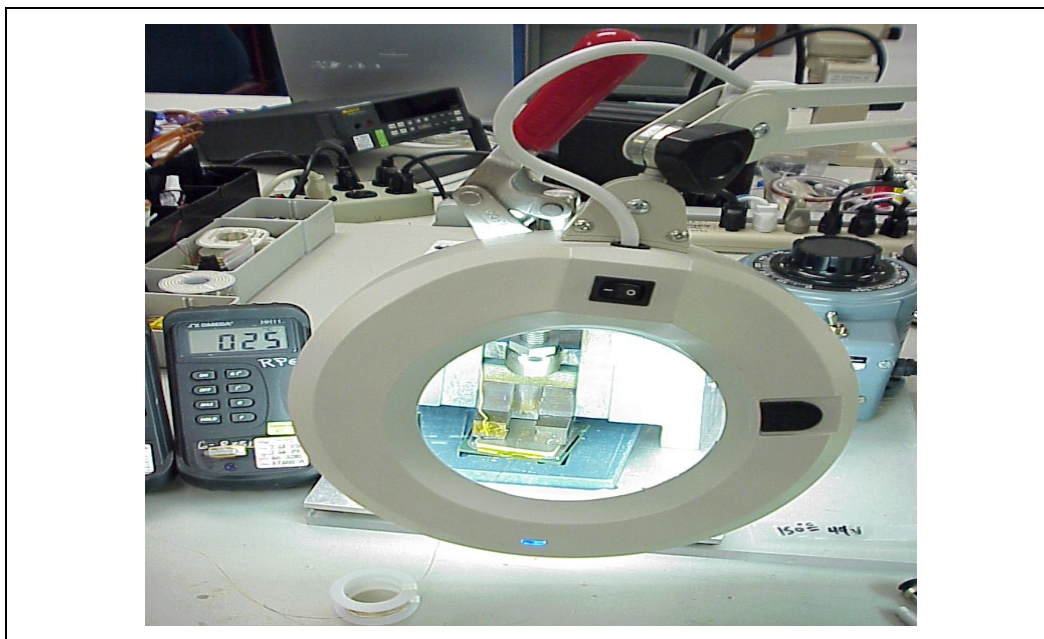
**Note:** Do Not touch the copper heater block at any time as this is very hot.

22. Move a magnified lens light close to the device in the solder status to get a better view when the solder begins to melt.
23. Lower the Heater block onto the IHS. Monitor the device IHS temperature during this step to ensure the maximum IHS temperature is not exceeded.

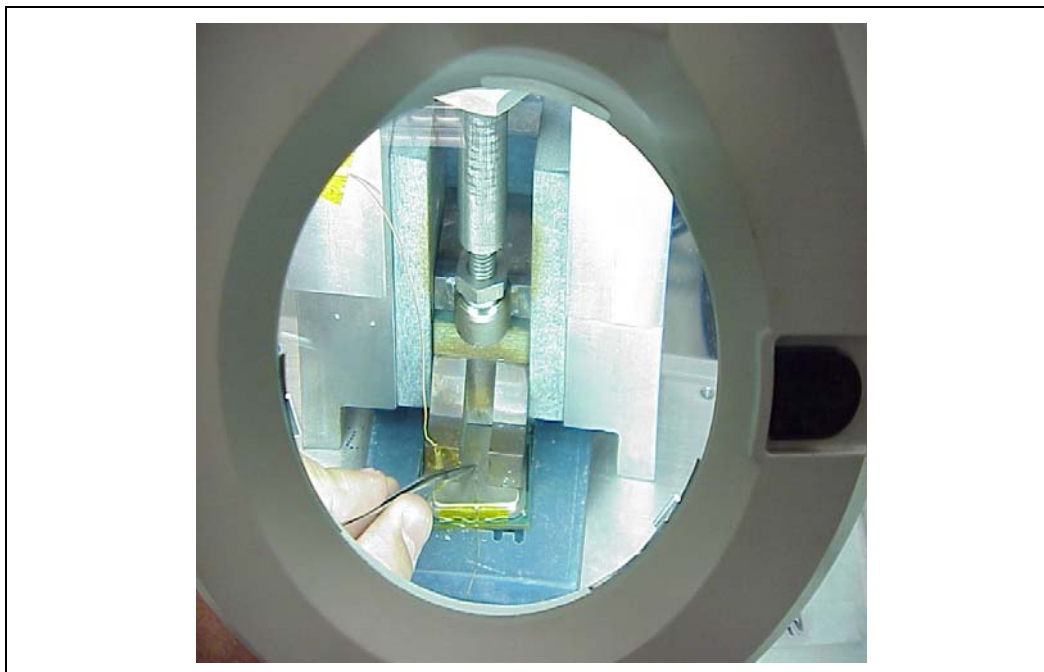
**Note:** The target IHS temperature during reflow is  $150\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ . At no time should the IHS temperature exceed  $155\text{ }^{\circ}\text{C}$  during the solder process as damage to the device may occur.

24. You may need to move the solder back toward the groove as the IHS begins to heat. Use a fine tip tweezers to push the solder into the end of the groove until a solder ball is built up (Figure 44 and Figure 45).

**Figure 44. View Through Lens at Solder Station**

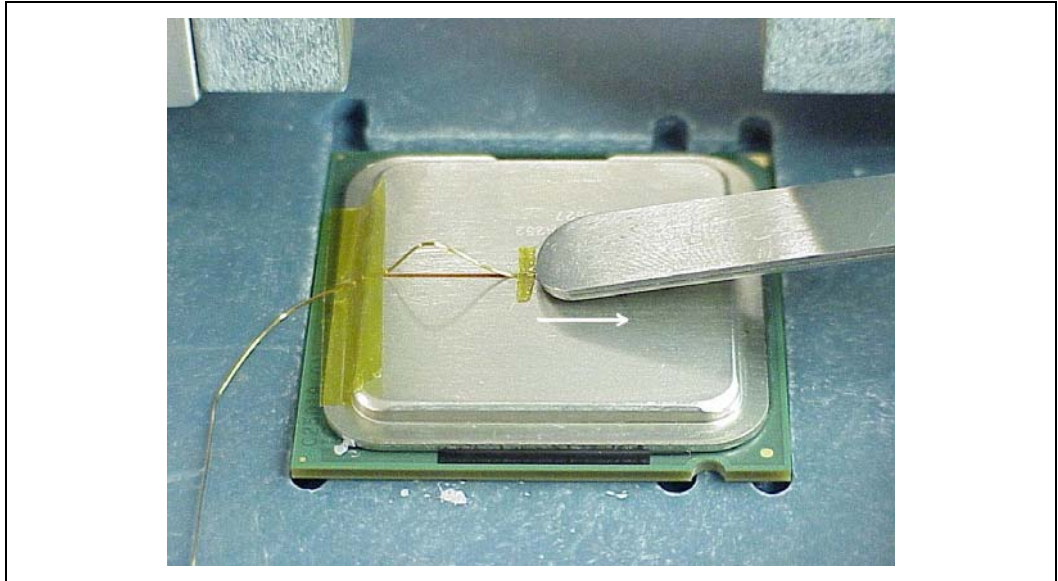


**Figure 45. Moving Solder back onto Thermocouple Bead**



25. Lift the heater block and magnified lens, using tweezers quickly rotate the device 90 degrees clockwise. Using the back of the tweezers press down on the solder this will force out the excess solder.

**Figure 46. Removing Excess Solder**



26. Allow the device to cool down. Blowing compressed air on the device can accelerate the cooling time. Monitor the device IHS temperature with a handheld meter until it drops below 50 °C before moving it to the microscope for the final steps.



## D.5.4 Cleaning and Completion of Thermocouple Installation

27. Remove the device from the solder station and continue to monitor IHS temperature with a handheld meter. Place the device under the microscope and remove the three pieces of Kapton\* tape with tweezers, keeping the longest for re-use.
28. Straighten the wire and work the wire in to the groove. Bend the thermocouple over the IHS. Replace the long piece of Kapton\* tape at the edge of the IHS.

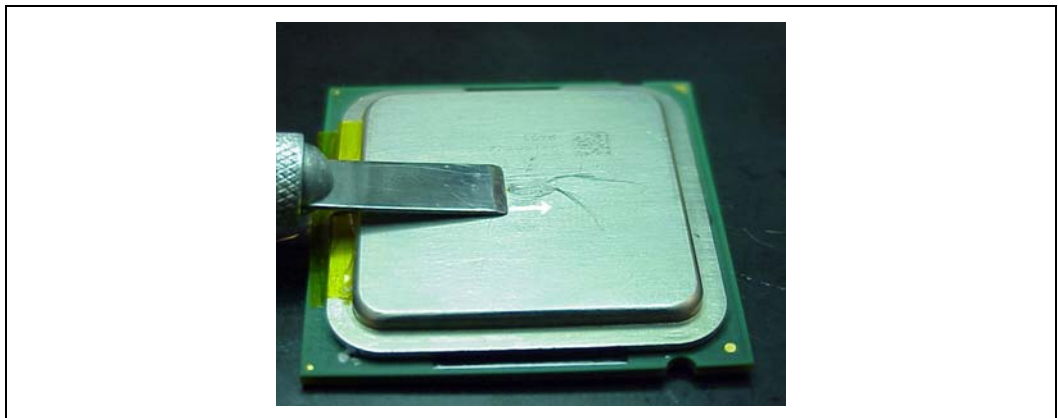
**Note:** The wire needs to be straight so it does not sit above the IHS surface at anytime (Figure 47).

**Figure 47. Thermocouple placed into groove**



29. Use a blade to carefully shave the excess solder above the IHS surface. Only shave in one direction until solder is flush with the groove surface (Figure 48).

**Figure 48. Removing Excess Solder**



**Note:** Take usual precautions when using open blades.

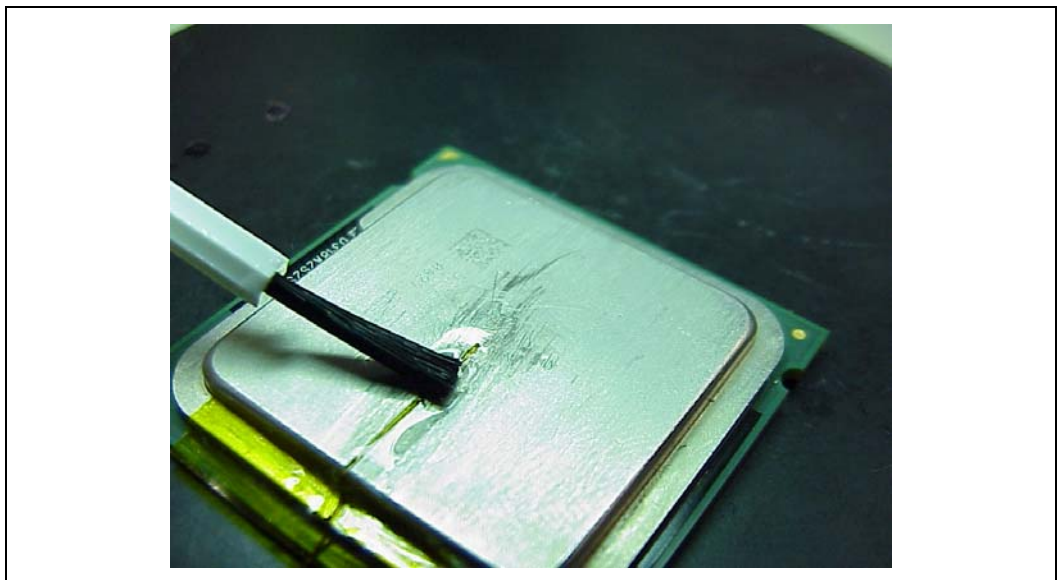
30. Clean the surface of the IHS with Alcohol and use compressed air to remove any remaining contaminants.
31. Fill the rest of the groove with Loctite\* 498 Adhesive. Verify under the microscope that the thermocouple wire is below the surface along the entire length of the IHS groove (Figure 49).

**Figure 49. Filling Groove with Adhesive**



32. To speed up the curing process apply Loctite\* Accelerator on top of the Adhesive and let it set for a couple of minutes (Figure 50).

**Figure 50. Application of Accelerant**

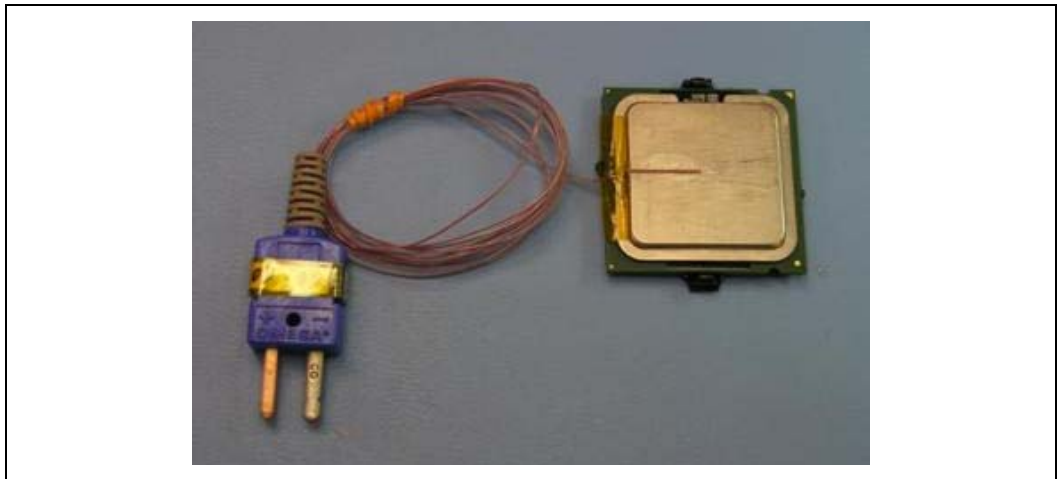


**Figure 51. Removing Excess Adhesive from IHS**

33. Using a blade, carefully shave any adhesive that is above the IHS surface (Figure 51). The preferred method is to shave from the edge to the center of the IHS.

**Note:** The adhesive shaving step should be performed while the adhesive is partially cured, but still soft. This will help to keep the adhesive surface flat and smooth with no pits or voids. If there are voids in the adhesive, refill the voids with adhesive and shave a second time.

34. Clean IHS surface with IPA and a wipe.
35. Clean the LGA pads with IPA and a wipe.
36. Replace the land side cover on the device.
37. Perform a final continuity test.
38. Wind the thermocouple wire into loops and secure or if provided by the vendor back onto the plastic roll. (Figure 52).

**Figure 52. Finished Thermocouple Installation**

39. Place the device in a tray or bag until it's ready to be used for thermal testing use.

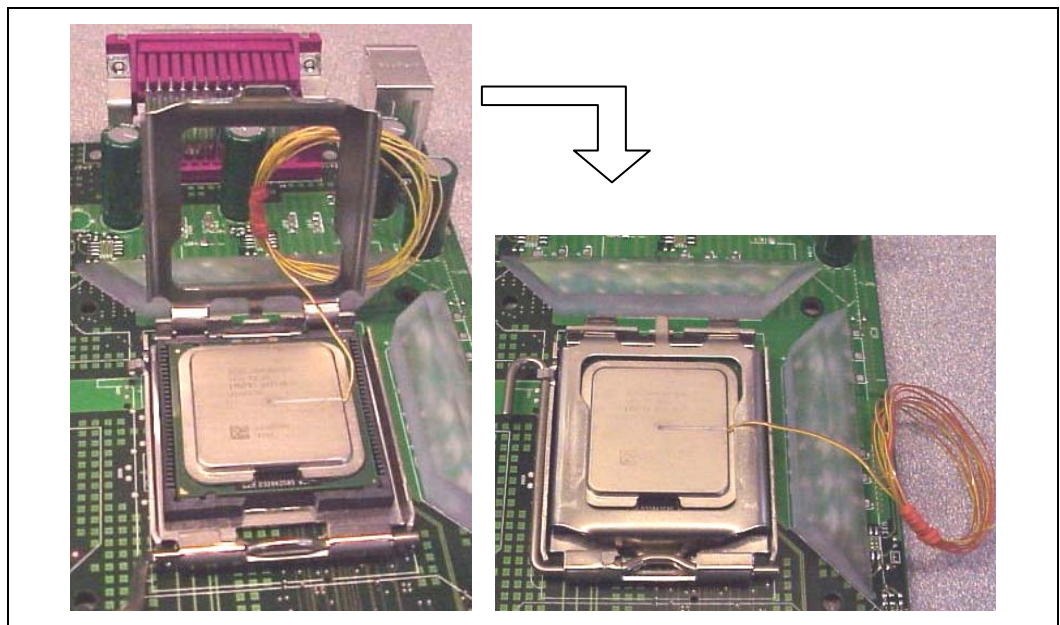
## D.6 Thermocouple Wire Management

When installing the processor into the socket, make sure that the thermocouple wires exit above the load plate as shown in Figure 53. Pinching the thermocouple wires between the load plate and the IHS will likely damage the wires.

**Note:** When thermocouple wires are damaged, the resulting reading maybe incorrect. For example, if there are any cuts into the wires insulation where the wires are pinched between the IHS and the load plate, the thermocouple wires can get in contact with each other at this location. In that case, the reported temperature would be at the edge of the IHS/socket load plate area. This temperature is usually much lower than the temperature at the center of the IHS.

Prior to installing the heatsink, make sure that the thermocouple wires remain below the IHS top surface, by running a flat blade on top of the IHS for example.

**Figure 53. Thermocouple Wire Management**







## Appendix E Board Level PWM and Fan Speed Control Requirements

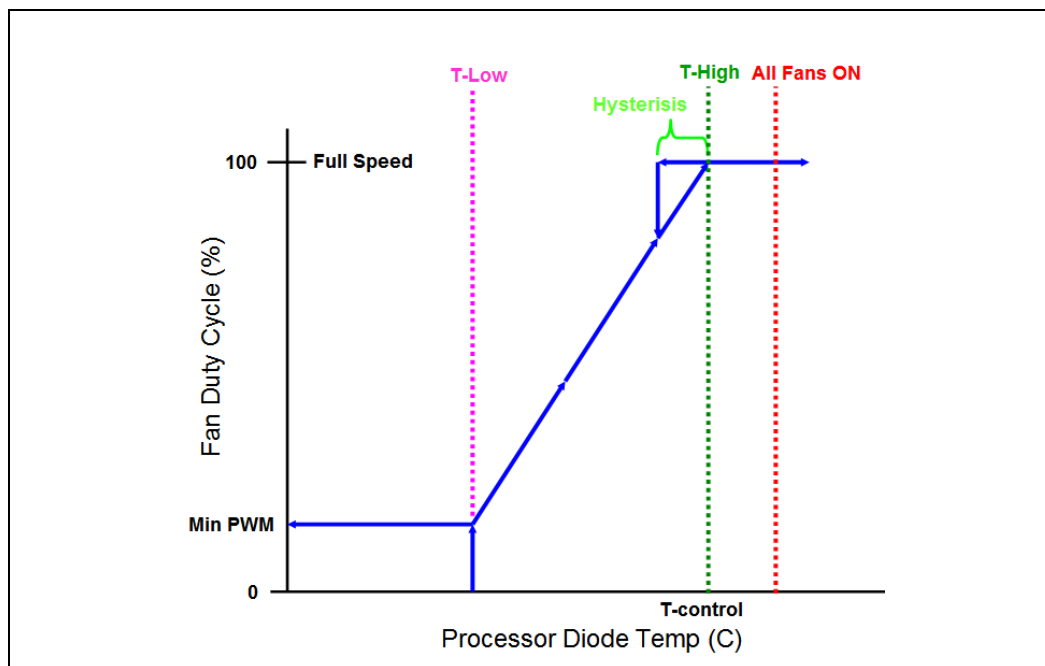
To use all of the features in the Intel reference heatsink design or the Boxed Intel processor, system integrators should verify the following functionality is present in the board design. Refer to the *Fan Specification for 4 wire PWM Controlled Fans* and Chapter 5 for complete details on the Intel enabled thermal solution.

The basics of Fan Speed Control are discussed in Chapter 6; as a review the FSC definitions are listed in Table 9.

**Table 9. FSC Definitions**

Item	Definition
$T_{\text{DIODE}}$	Temperature reported from the processor on-die thermal diode.
$T_{\text{CONTROL}}$	$T_{\text{CONTROL}}$ is the specification limit for use with the on-die thermal diode
Thermal Diode Offset	Thermal Diode Offset is the MSR value programmed into the Pentium 4 processor sequence 6x1, Pentium processor Extreme Edition 955, 965, and Pentium D processor 900 sequence diode to account for perceived diode ideality shift.
Thermal Diode Base	The constant published in the processor datasheet for calculating Thermal Diode Correction Factor
Thermal Diode Correction Factor	Thermal Diode Correction Factor is the sum of the Thermal Diode Offset and Thermal Diode Base. This value is used to compensate for temperature errors if the diode ideality factor is near the maximum or minimum values. It is only used for hardware monitor components that measure the on-die thermal diode using the diode model.
$T_{\text{LOW}}$	The temperature above which the fan will begin to accelerate in response to the on-die thermal diode temperature.
Hysteresis	The number of degrees below $T_{\text{control}}$ the fans will remain on before slowing down.
$T_{\text{HIGH}}$	The temperature at which the fan is operating at full speed (100% PWM Duty Cycle). By specification this is $T_{\text{control}}$ .
All Fans ON	The processor temperature at which all fans in the system are increased to 100% Duty Cycle.
Min PWM	Minimum pulse width modulation (% duty cycle) that the fans will run at when $T_{\text{DIODE}}$ is less than $T_{\text{LOW}}$ .
Spin-up	Amount of time fan is run at 100% duty cycle to overcome fan inertia.
PWM Freq	The operating frequency of the PWM signal.
$T_{\text{AVERAGING}}$	The time (in seconds) that elapses while the fan is gradually sped up in response to a processor temperature spike.

Figure 54. FSC Definition Example



#### Requirements Classification

- Required – an essential part of the design necessary to meet specifications. Should be considered a pass or fail criterion in selection of a board.
- Suggested – highly desired for consistency among designs. May be specified or expanded by the system integrator.

The motherboard needs to have a fan speed control component that has the following characteristics:

- PWM output programmable to 21–28 kHz (required). PWM output set to 25 kHz (Suggested) as this value is the design target for the reference and for the Boxed Processor.
- External/remote thermal diode measurement capability (required).
- External/remote thermal diode sampling rate  $\geq 4$  times per second (required).
- External/remote diode measurement is calibrated by the component vendor to account for the diode ideality and package series resistance as listed in the appropriate datasheet. (Suggested).

**Note:** If the fan speed controller is not calibrated with the diode ideality and package series resistance, verify the board manufacturer has made provisions within the BIOS setup or other utility to input the corrections factors.

The BIOS, at a minimum, must program the settings in Table 10 or Table 11 into the fan speed controller. The values are the minimum required to establish a fan speed control algorithm consistent with this document, the reference thermal solution and Boxed Processor thermal solution.



Table 10. ATX FSC Settings

Parameter	Classification	Processor Thermal Diode	PWM Output	Notes
$T_{HIGH}$	Required	$T_{CONTROL}$		3, 5
$T_{LOW}$	Required	$T_{CONTROL} - 10\text{ }^{\circ}\text{C}$		3, 5
Minimum PWM Duty Cycle	Required		20%	
PWM Frequency	Required		21–28 kHz	1
Spin-up time	Suggested		250 – ~500 ms	2, 6
$T_{AVERAGING}$	Suggested	35 sec		6
When $T_{DIODE} < T_{LOW}$	Suggested	Minimum PWM%		
All Fans ON	Suggested	$T_{CONTROL} + 3\text{ }^{\circ}\text{C}$		
Hysteresis	Suggested	2 $^{\circ}\text{C}$		
Offset	Required	Thermal Diode Correction Factor		4, 5

**NOTES:**

1. A PWM output set to 25 kHz is the design target for the reference and for the Boxed Intel Processor and the reference design.
2. Use the lowest time available in this range for the device selected.
3. To ensure compliance with the thermal specification, thermal profile and usage of the  $T_{DIODE}$  for fan speed control these setting should not be user configurable.
4. If present in the FSC device, the Thermal Diode Correction Factor should be input to this register.
5. If the FSC device does not have a means to input a fixed temperature offset then:  
 $T_{HIGH} = T_{CONTROL} + \text{Thermal Diode Correction Factor}$  and  
 $T_{LOW} = T_{CONTROL} + \text{Thermal Diode Correction Factor}$ .
6. If this function is present on the device, it must be enabled



Table 11. Balanced Technology Extended (BTX) FSC Settings

Parameter	Classification	Processor Thermal Diode	System Ambient Diode	PWM Output	Notes
$T_{HIGH}$	Required	$T_{CONTROL}$	54 °C		3,5,9
$T_{LOW}$	Required	$T_{CONTROL} - 7\text{ °C}$	47 °C		3,5,9
Minimum PWM Duty Cycle	Required			PWM 1 (TMA) –20%	
PWM Frequency	Required			21 – 28 kHz	1
Spin Up Time	Suggested			250 – ~ 500 ms	2,7
$T_{AVERAGING}$	Suggested	4.0 sec	4.0 sec		3,7
When $T_{DIODE} < T_{LOW}$	Suggested	Minimum PWM%	Minimum PWM%		
All Fans On	Suggested	$T_{CONTROL} + 3\text{ °C}$	65 °C		
Hysteresis	Suggested	2 °C	4 °C		
Offset	Required	Thermal Diode Correction Factor			8,9

**NOTES:**

1. A PWM frequency of 25 kHz is the design target for the reference and for the Intel Boxed processor and the reference design.
2. Use the lowest time available in this range for the device selected
3.  $T_{AVERAGING}$  = represents the amount of delay time before responding to the temperature change, defined in fan speed control device (sometimes called ramp range control or spike smoothing). Select the lowest setting available close to 4.0 seconds by the fan speed control device.
4. The Fan Speed Controller, or Health Monitor Component, takes the result of the two fan speed ramps (processor and system) and drives the TMA fan to the highest resulting PWM duty cycle (%)
5. For BTX systems. a second thermal sensor is recommended to capture chassis ambient temperature. For more detail, see Appendix F.
6. To ensure compliance with the thermal specification, thermal profile and usage of the  $T_{DIODE}$  for fan speed control these setting should not be user configurable.
7. If this function is present on the device, it must be enabled
8. If present in the FSC device, the Thermal Diode Correction Factor should be input to this register.
9. If the FSC device does not have a means to input a fixed temperature offset then:  
 $T_{HIGH} = T_{CONTROL} + \text{Thermal Diode Correction Factor}$  and  
 $T_{LOW} = T_{CONTROL} + \text{Thermal Diode Correction Factor}$

**Note:** The fan speed component vendors provide libraries that are used by the BIOS writer to program the component registers with the parameters listed above. Consult the appropriate vendor datasheet for detailed information on programming their component.



## Appendix F Balanced Technology Extended (BTX) System Thermal Considerations

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There are anticipated system operating conditions in which the processor power may be low but other system component powers may be high. If the only Fan Speed Control (FSC) circuit input for the Thermal Module Assembly (TMA) fan is from the processor diode then the fan speed and system airflow is likely to be too low in this operating state. Therefore, it is recommended that a second FSC circuit input be acquired from an ambient temperature monitor location within the system.

The location of the System Monitor thermal sensor is best determined through extensive system-level numerical thermal modeling or prototype thermal testing. In either case, the temperature of critical components or the air temperature near critical components should be assessed for a range of system external temperatures, component powers, and fan speed operating conditions. The temperature at the selected location for the System Monitor Point should be well correlated to the temperatures at or near critical components. For instance, it may be useful to monitor the temperature near the PSU airflow inlet, near the graphics add-in card, or near memory.

The final system integrator is typically responsible for ensuring compliance with the component temperature specifications at all operating conditions and, therefore, should be responsible for specifying the System Monitor thermal sensor location. However, it is not always possible for a board supplier – especially a channel board supplier – to know the system into which a board will be installed. It is, therefore, important for BTX board suppliers to select a System Monitor thermal sensor location that will function properly in most systems.

A BTX system should be designed such that the TMA exhaust is the primary airflow stream that cools the rest of the system. The airflow passes through the chipset heatsink and its temperature will rise as the memory controller chipset power increases. Since chipset power will increase when other subsystems (e.g., memory, graphics) are active, a System Monitor thermal sensor located in the exhaust airflow from the chipset heatsink is a reasonable location.

It is likely that a thermal sensor that is not mounted above the board and in the chipset exhaust airflow will reflect board temperature and not ambient temperature. It is, therefore, recommended that the thermal sensor be elevated above the board.

The thermal sensor location and elevation are reflected in the Flotherm thermal model airflow illustration and pictures (see Figure 55 and Figure 56). The Intel® Boxed Boards in BTX form factor have implemented a System Monitor thermal sensor. The following devices, or their equivalent, can be used for this function:

Part Number: C83274-002  
BizLink USA Technology, Inc.  
44911 Industrial Drive  
Fremont, CA 94538 USA  
(510)252-0786 phone  
(510)252-1178 fax  
[sales@bizlinktech.com](mailto:sales@bizlinktech.com)

Part Number: 68801-0170  
Molex Incorporated  
2222 Wellington CT  
Lisle, IL 60532  
1-800-78MOLEX  
1-630-969-1352  
[amerinfo@molex.com](mailto:amerinfo@molex.com)

Figure 55. System Airflow Illustration with System Monitor Point Area Identified

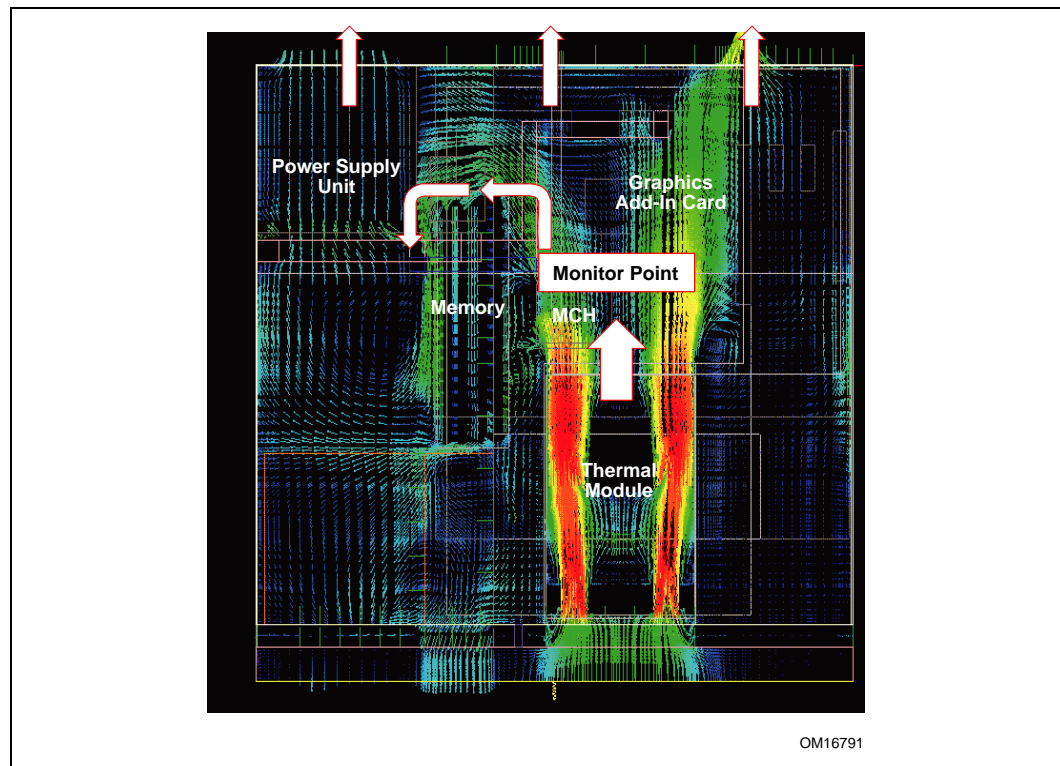
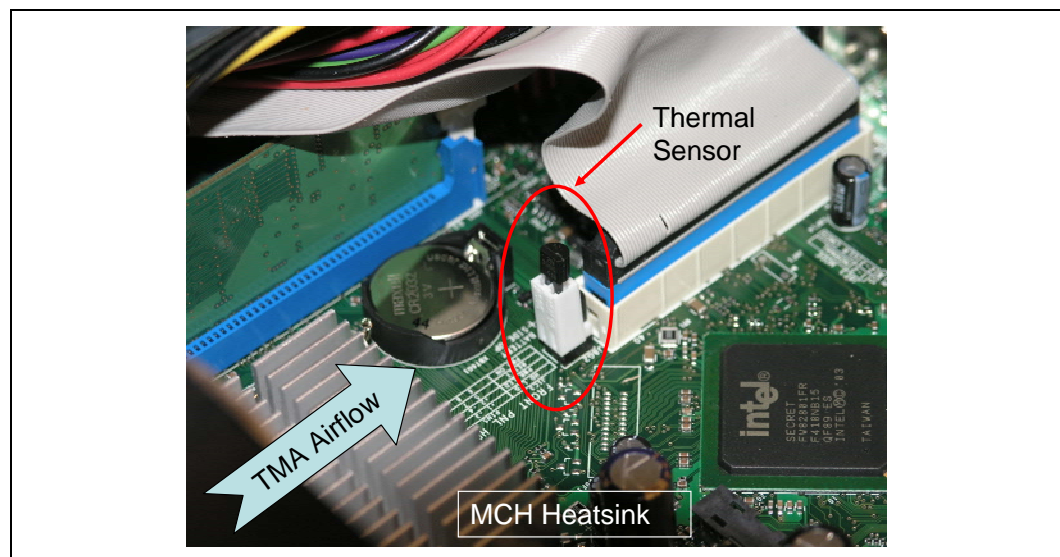


Figure 56. Thermal Sensor Location Illustration



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## Appendix G Mechanical Drawings

The following table lists the mechanical drawings included in this appendix. These drawings refer to the reference thermal mechanical enabling components for the processor.

**Note:** Intel reserves the right to make changes and modifications to the design as necessary.

Drawing Description	Page Number
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 1)	104
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 2)	105
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 3)	106
Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 1)	107
Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 2)	108
Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 3)	109
Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 4)	110
Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 5)	111
ATX Reference Clip (Sheet 1)	112
ATX Reference Clip (Sheet 2)	113
Reference Fastener (Sheet 1)	114
Reference Fastener (Sheet 2)	115
Reference Fastener (Sheet 3)	116
Reference Fastener (Sheet 4)	117
Intel® RCFH-4 Reference Solution Assembly	118
Intel® RCFH-4 Reference Solution Assembly (Sheet 2)	119

Figure 57. ATX/ $\mu$ ATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components  
(Sheet 1)

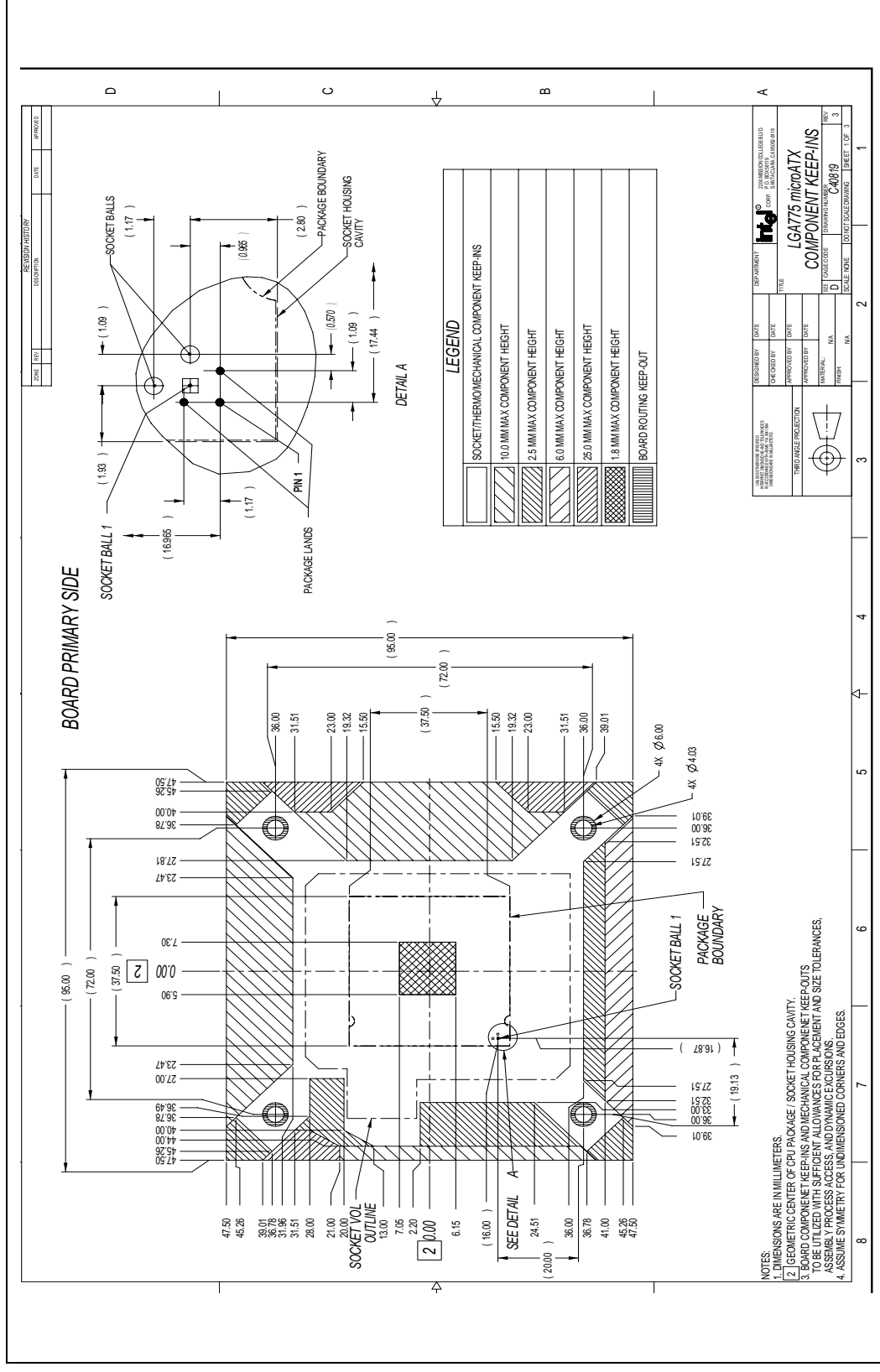
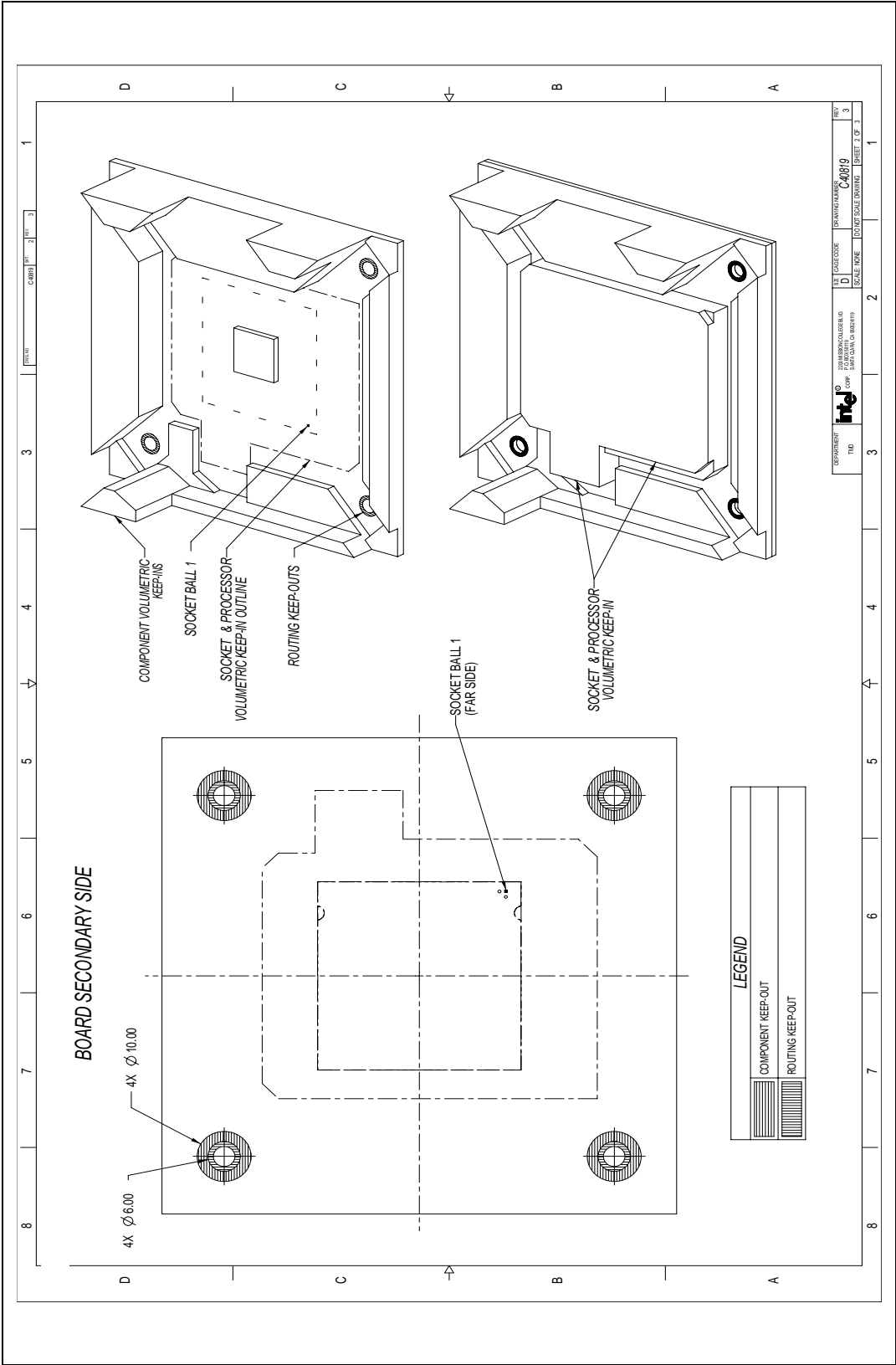






Figure 58. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 2)



106

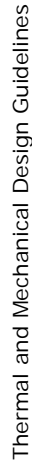


Figure 60. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 1)

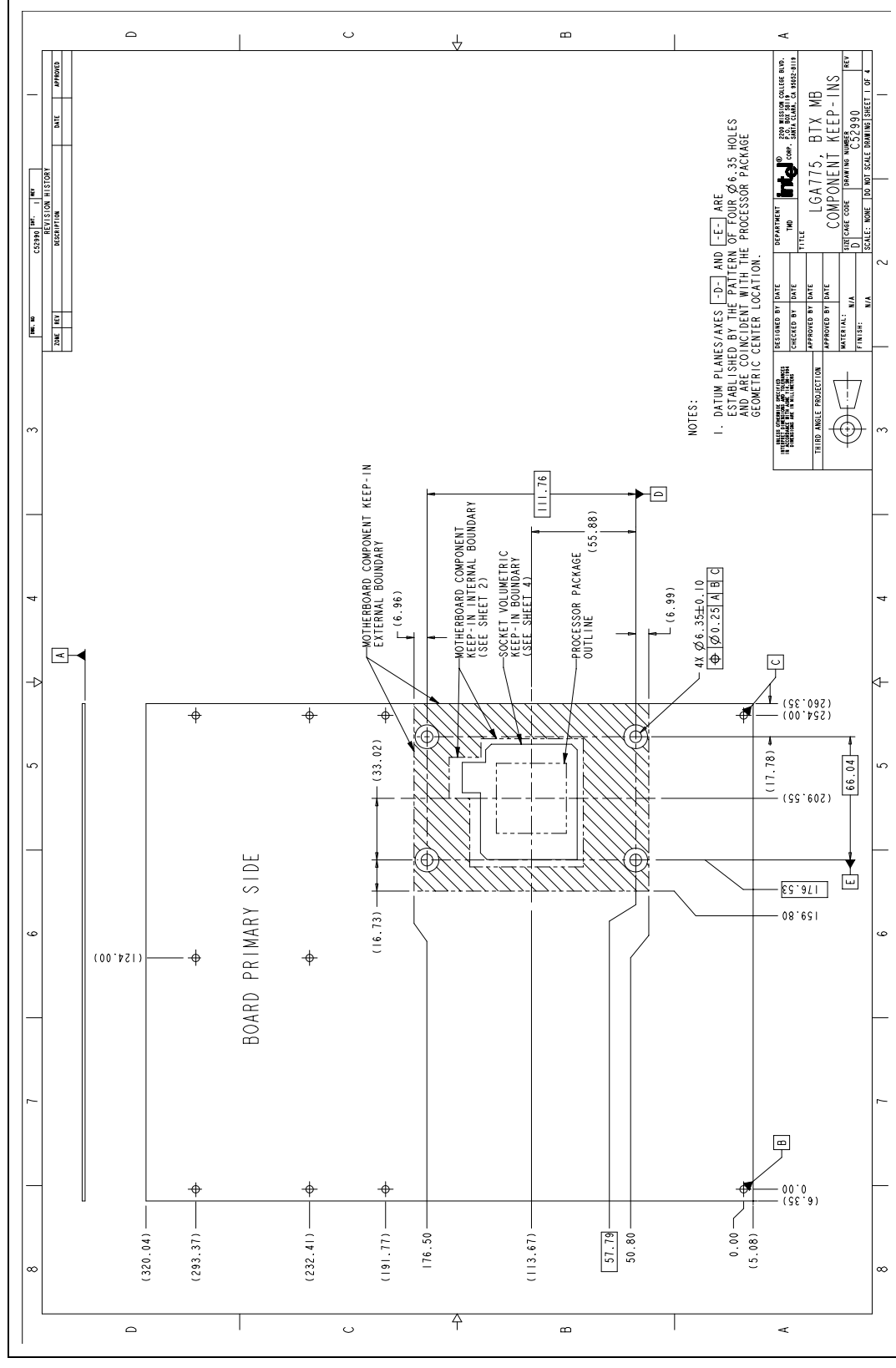


Figure 61. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 2)

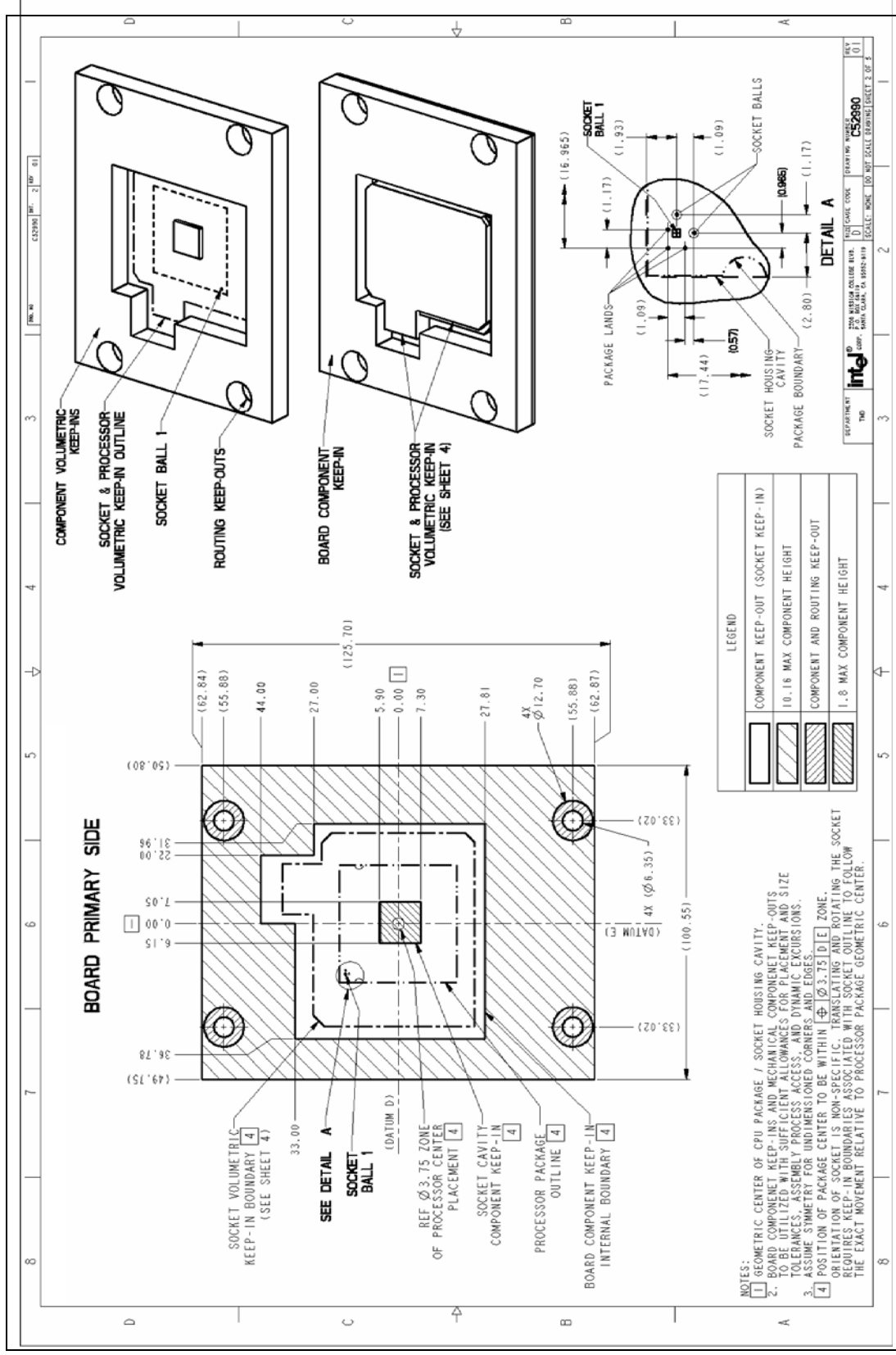
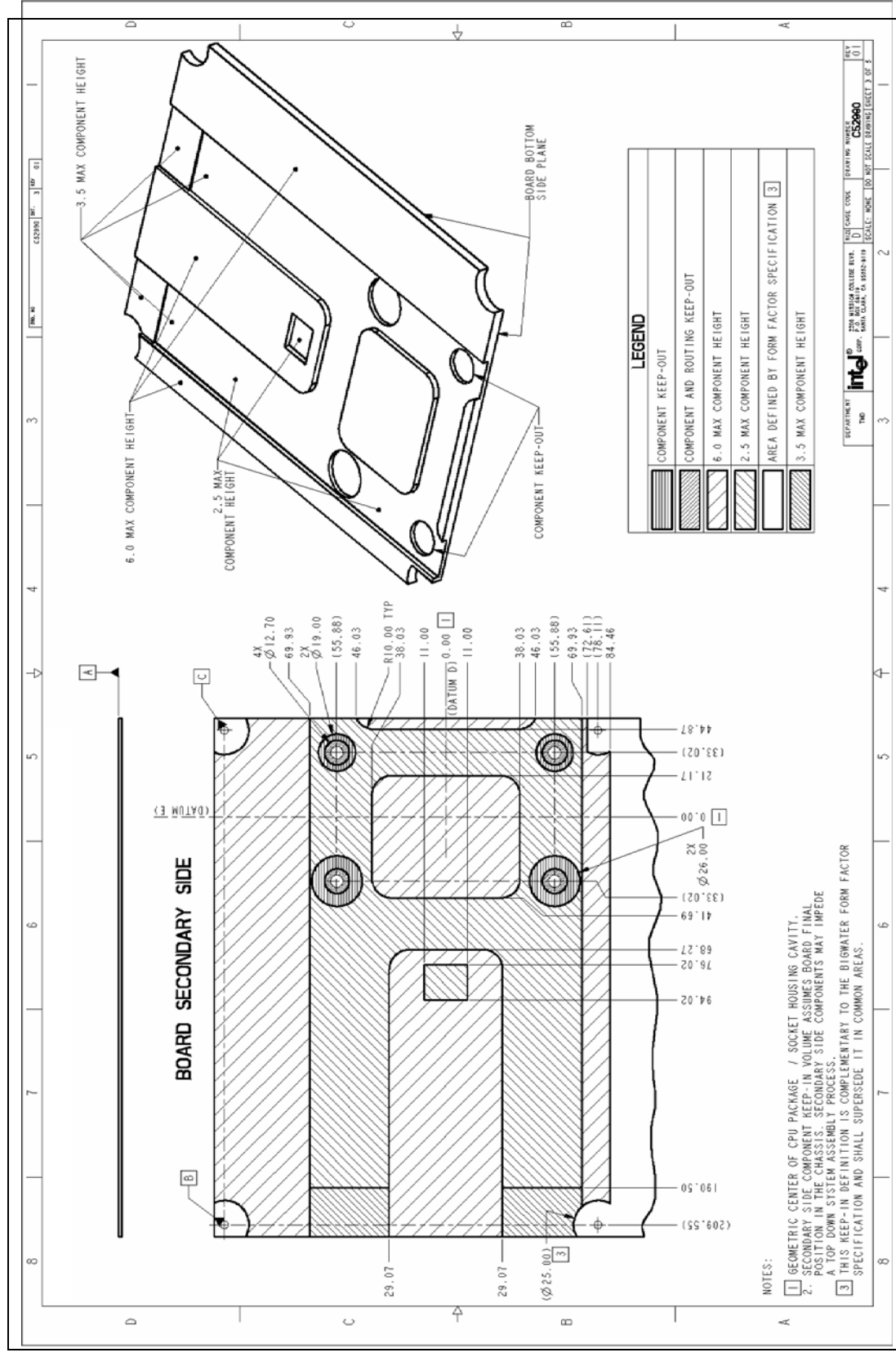


Figure 62. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 3)



**SOCKET & PROCESSOR VOLUMETRIC KEEP-IN**

**TOP SIDE VIEW**

**BOTTOM SIDE VIEW**

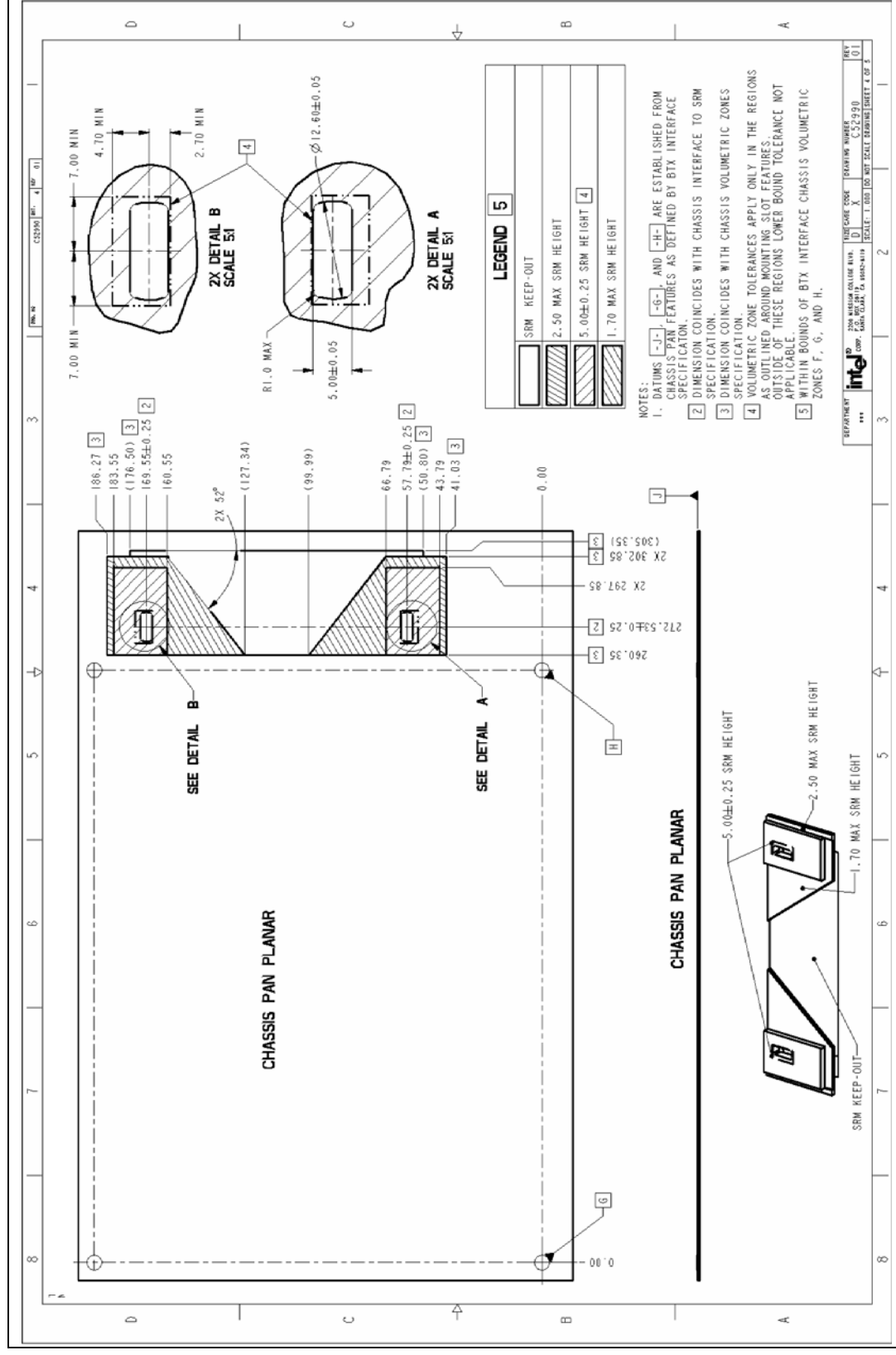
**SECTION A-A**

**LEVER MOTION SPACE REQUIRED TO RELEASE SOCKET LOAD PLATE**

**NOTES:**

1. SOCKET CENTER PLANES ARE REFERENCED FROM GEOMETRIC CENTER OF SOCKET HOUSING CAVITY FOR CPU PACKAGE (ALIGNS WITH DATUM REFERENCE GIVEN FOR BOARD COMPONENT KEEP-INS).
2. SOCKET KEEP-IN VOLUME VERTICAL HEIGHT ESTABLISHES LIMIT OF SOCKET AND CPU PACKAGE ASSEMBLY IN THE SOCKET LOCKED DOWN POSITION. IT ENCOMPASSES SOCKET AND CPU PACKAGE DIMENSIONAL TOLERANCES AND DEFLECTION / SHAPE CHANGES DUE TO DSL LOAD.
3. SOCKET KEEP-IN VOLUME ENCOMPASSES THE SOCKET NOMINAL VOLUME AND ALLOWANCES FOR SIZE TOLERANCES. THERMAL/MECHANICAL COMPONENT DEVELOPERS SHALL DESIGN TO THE OUTSIDE OF SOCKET KEEP IN VOLUME WITH CLEARANCE MARGINS. SOCKET DEVELOPERS SHALL DESIGN TO THE INSIDE VOLUME.

Figure 64. Balanced Technology Extended (BTX) Thermal Module Keep-out Volumetric (Sheet 5)



[illegible]



**DETAIL A**  
SCALE 10  
TYPICAL 4 PLACES

**DETAIL B**  
SCALE 20

**SECTION D-D**  
SCALE 8

**DETAIL C**  
SCALE 10  
TYP 4 PLACES

THIS POINT CORRESPONDS TO THE 30.6 DIMENSION ON SHEET 1 ZONE A17

**PROJECT INFORMATION**

PROJECT NAME	2000 WILSON COLLEGE BLVD	DATE	10/10/2000
PROJECT NUMBER	C85609	DATE	10/10/2000
PROJECT	1	DATE	10/10/2000
PROJECT	1	DATE	10/10/2000

114

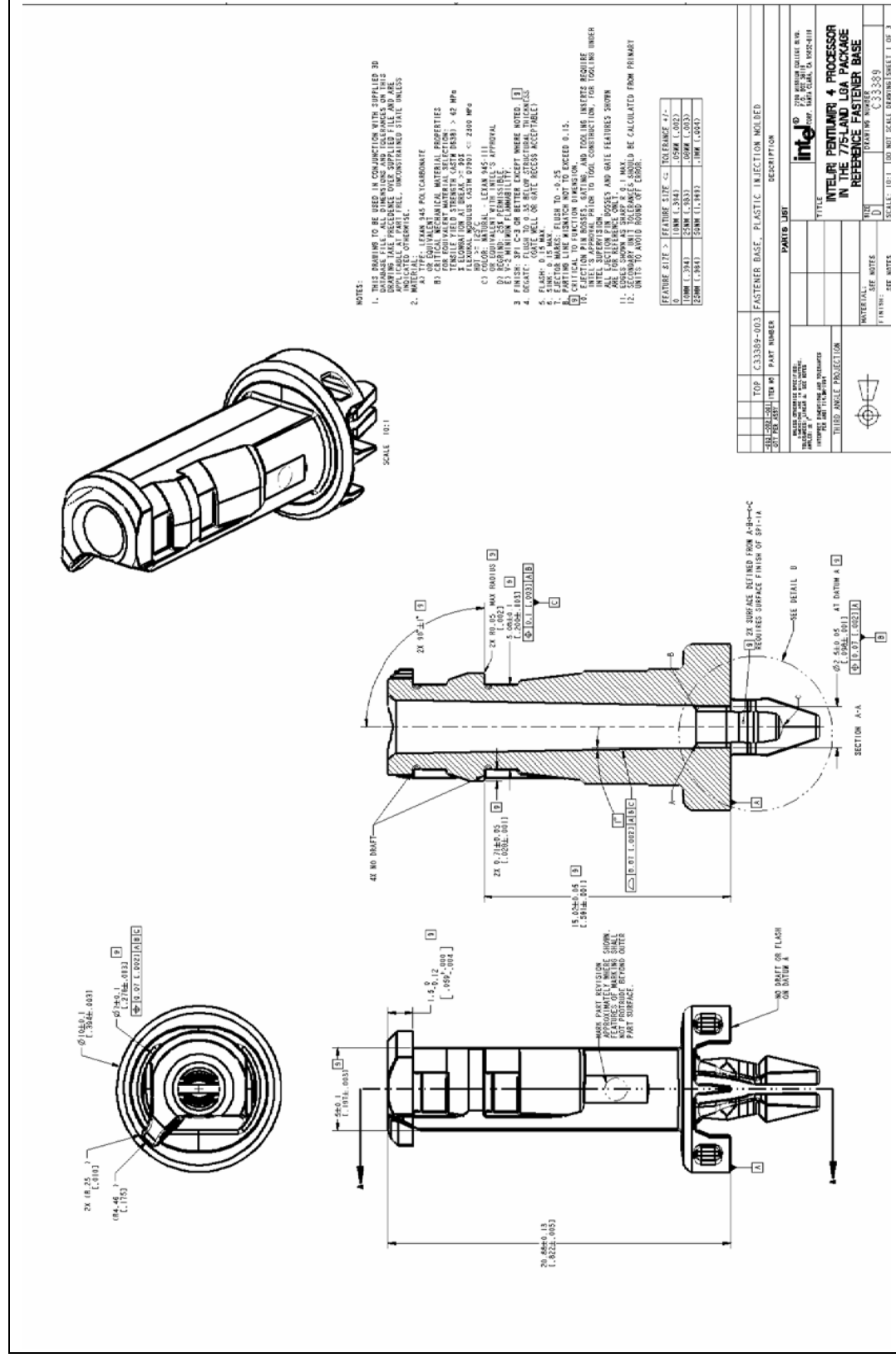
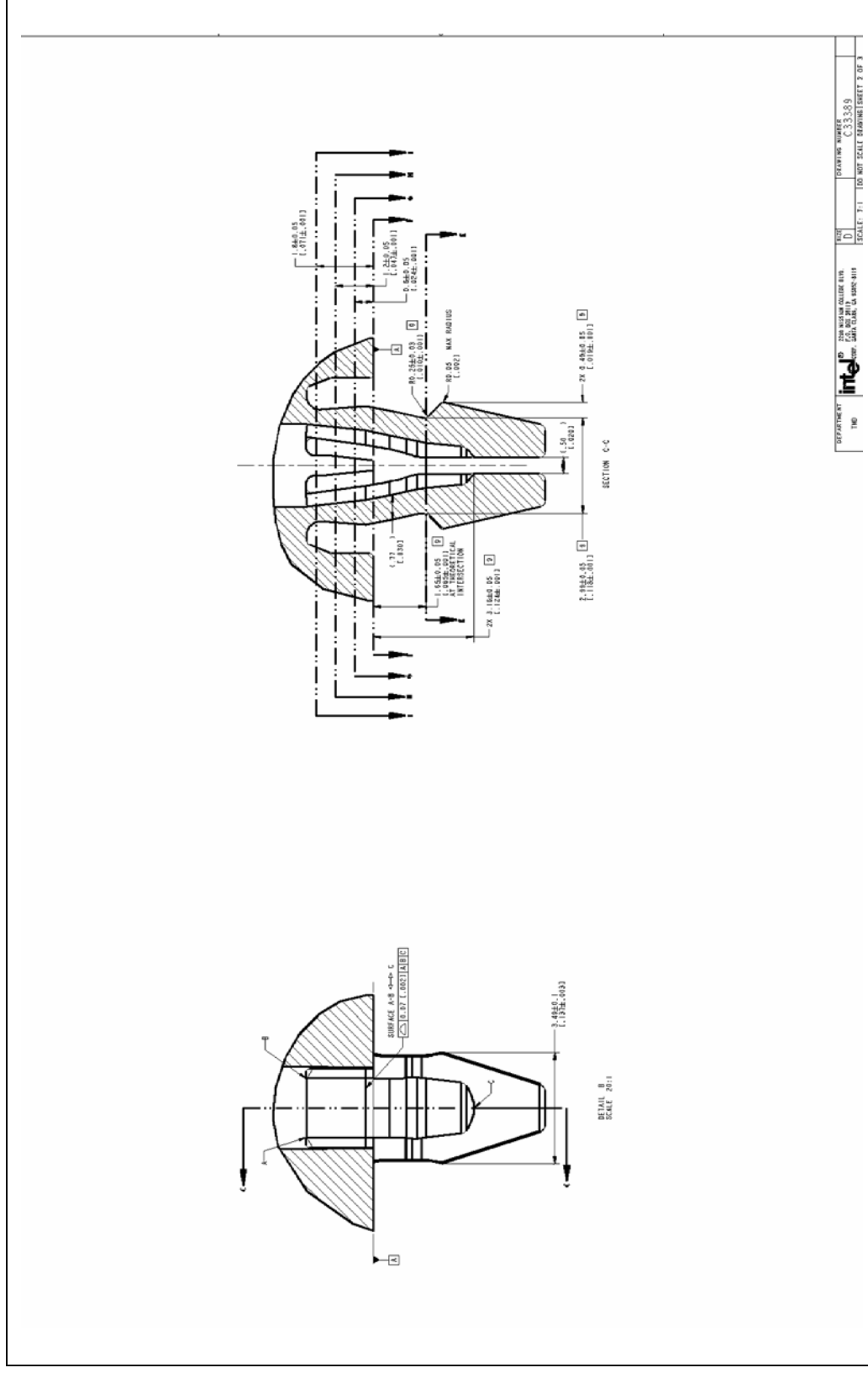


Figure 68. Reference Fastener (Sheet 2)



**Figure 69. Reference Fastener (Sheet 3)**

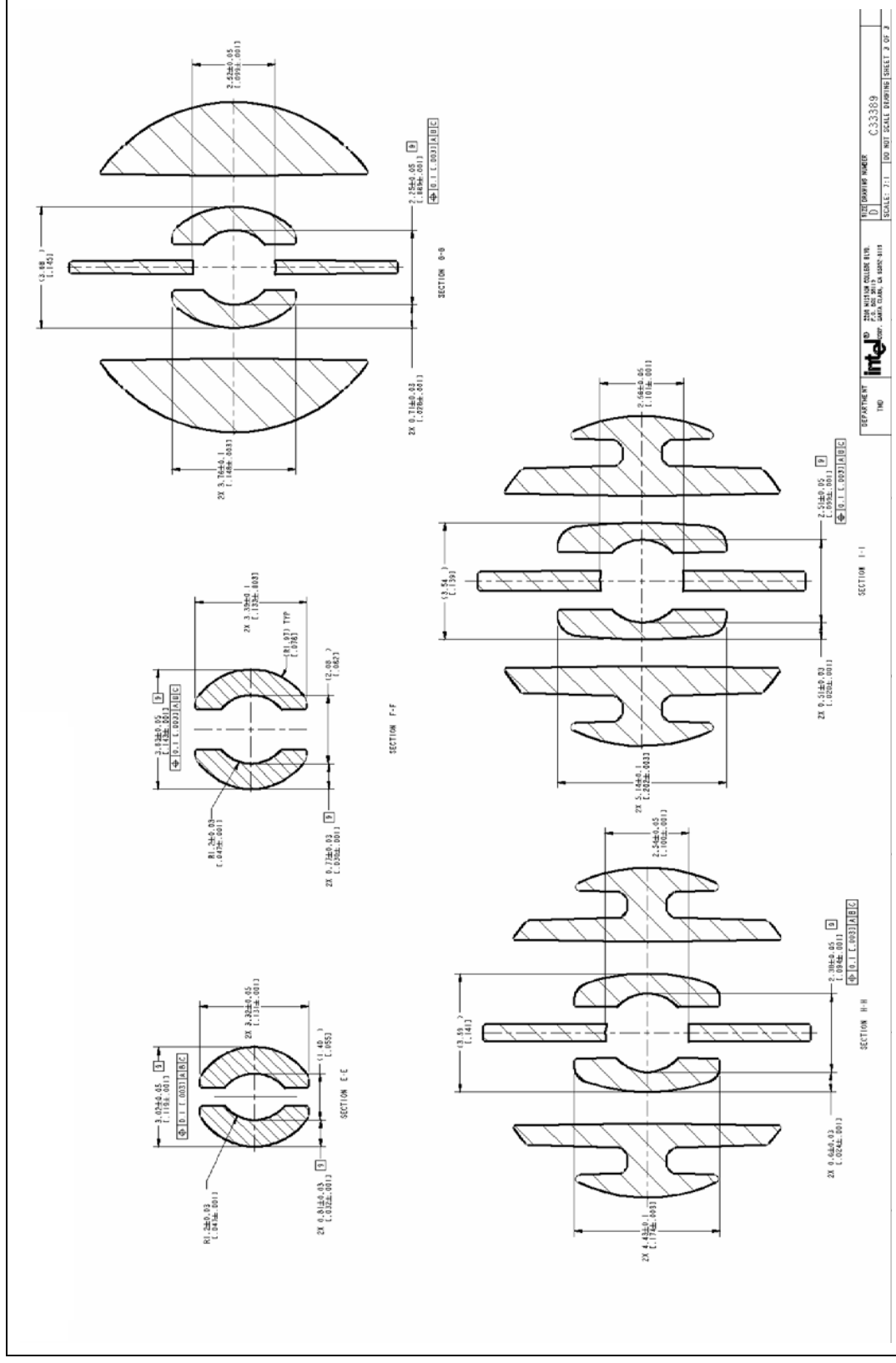
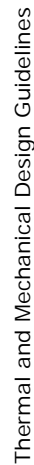


Figure 70. Reference Fastener (Sheet 4)

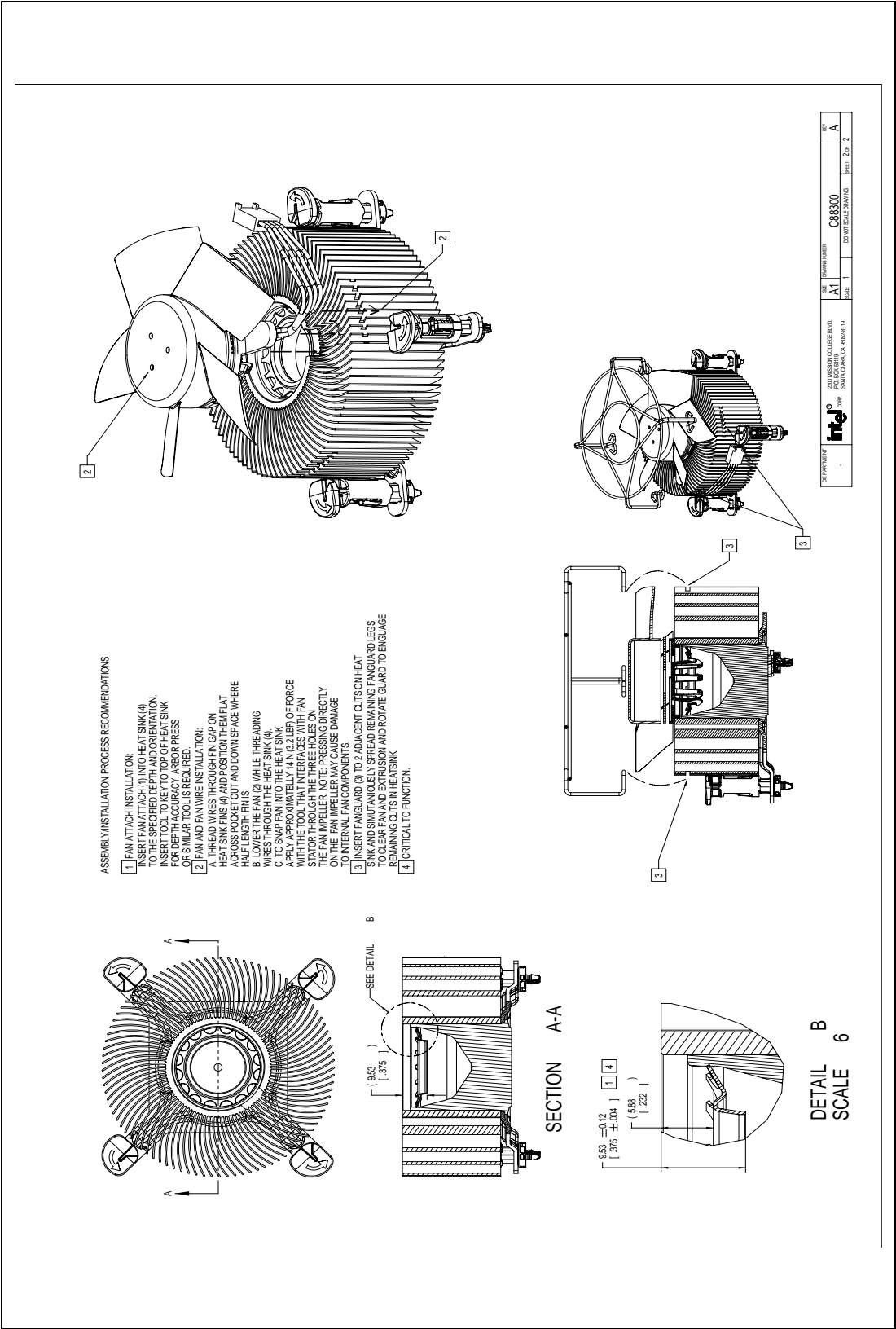


118





Figure 72. Intel® RCFH-4 Reference Solution Assembly (Sheet 2)









## Appendix H Intel® Enabled Reference Solution Information

This appendix includes current supplier information for Intel enabled vendors for the reference thermal solution supporting the Intel Pentium D processor 800 and 900 sequences, Intel Pentium processor Extreme Edition 840, 955, 965, and Intel Pentium 4 processor 6x1 sequence.

The reference component designs are available for adoption by suppliers and heatsink integrators pending completion of appropriate licensing contracts. For more information on licensing, contact the Intel representative mentioned in Table 12.

**Table 12. Intel® Representative Contact for Licensing Information**

Company	Contact	Phone	Email
Intel Corporation	Travis Ness	(253) 371-9169	<a href="mailto:travis.b.ness@intel.com">travis.b.ness@intel.com</a>

Table 13 and Table 14 lists current suppliers that produce Intel enabled reference components for 775\_VR\_CONFIG\_05B processors (TDP = 130 W). End-users are responsible for the verification of the Intel enabled component offerings with the supplier. OEMs and System Integrators are responsible for thermal, mechanical, and environmental validation of these solutions.

**Table 13. Intel® Reference Component ATX Thermal Solution Providers**

Supplier	Part Description	Part Number	Contact	Phone	Email
CCI* (Chaun-Choung Technology Corp.)	RCFH-4 Reference Heatsink	00I830901A	Harry Lin Monica Chih	714-739-5797 +886-2-29952666 Extension 131	ackinc@aol.com <a href="mailto:monica_chih@ccic.com.tw">monica_chih@ccic.com.tw</a>
AVC* (ASIA Vital Components Co., Ltd)	RCFH-4 Reference Heatsink	Z9U703K001	David Chao	+886-2-22996930 Extension: 619	david_chao@avc.com.tw
Sunon*	RCFH-4 Fan Assembly	PMD1209PKB1-A. (2).B1397.F	Tom Blaskovich	714-255-0208 extension 206	tomb@sunon.com
ITW Fastex*	Fastener	Base: C33389 Cap: C33390	Ron Schmidt	847-299-2222	<a href="mailto:rschmidt@itwfastex.com">rschmidt@itwfastex.com</a>



**Note:** For the Intel enabled reference ATX components for 775\_VR\_CONFIG\_05A processors (TDP = 95 W) in see *Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal and Mechanical Design Guidelines* available at: <http://www.intel.com/design/Pentium4/guides/302553.htm> for information on the RCBFH-3.

**Table 14. Intel® Reference Component for Balanced Technology Extended (BTX) Thermal Solution Providers**

Supplier	Part Description	Part Number	Contact	Phone	Notes
Mitac International Corp	Support and Retention Module	342011700003	Michael Tsai	886-3-328-9000 Ext.6545	
AVC* (ASIA Vital Components Co., Ltd)	Type I Thermal Module Fan Assembly	DB09238B120084	David Chao	+886-2-22996930 Extension: 619	1
AVC* (ASIA Vital Components Co., Ltd)	Type II Thermal Module Fan Assembly	DB07038B12UP001	David Chao	+886-2-22996930 Extension: 610	1

**NOTES:**

1. The following for the 2004 Type I and Type II Intel reference Thermal Module Assemblies:
  - a) 2004 Type I TMA meets the requirements for the Pentium D processor and Pentium processor Extreme Editions for 775\_VR\_CONFIG\_05B processors,
  - b) 2004 Type II TMA does not meet the requirements for 775\_VR\_CONFIG\_05B processors; however, it does meet the requirements for Pentium D processor for 775\_VR\_CONFIG\_05A processors.

**Note:** These vendors/devices in Table 13 and Table 14 are listed by Intel as a convenience to Intel's general customer base, but Intel does not make any representations or warranties whatsoever regarding quality, reliability, functionality, or compatibility of these devices. This list and/or these devices may be subject to change without notice.

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